# CALIFORNIA STRAWBERRY COMMISSION

# PEST MANAGEMENT ALLIANCE STUDY REPORT

**for**

# An Evaluation of Soil-Borne Pest Management for Strawberries in California in the Absence of Methyl Bromide

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**An Evaluation of Soil-Borne Pest Management for Strawberries in California in the Absence of Methyl Bromide**

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## Abstract

Tests of fumigation treatments as alternates to those containing methyl bromide have been completed by the Pest Management Alliance team composed of researchers from several organizations. The organizations include the California Strawberry Commission (CSC), the University of California (UC) and its Extension Service , the United States Department of Agriculture's Agricultural Research Service (USDA-ARS), the California Integrated Waste Management Board (IWMB), the California Department of Food and Agriculture (CDFA), and members of the crop protection industry.

The overall finding is that fumigation of beds using chemical alternatives to methyl bromide appears technically feasible, but requires additional study and development to demonstrate pest control efficacy and economic viability under current and proposed pesticide use regulations. A series of trials completed over a 2-year period showed that the alternate treatment Telone/chloropicrin by either shank injection or *via* a drip system is equivalent or superior to broadcast fumigation of methyl bromide/chloropicrin, today's standard treatment, for control of soil microoganisms affecting strawberries in the studies conducted. Additional studies must be conducted to verify this over the range of environments and conditions under which strawberries are produced, and regulatory restrictions addressed such that this treatment may be economically viable for a significant portion of the strawberry production acreage. Mulching with VIF (virtually impermeable plastic film) potentially offers utility by maintaining yields with alternate fumigants while reducing application rates. However, development of a VIF of a consistent quality with the requisite mechanical properties, and making such affordable and available in commercial volume remains to be done.

One-year crop rotations without fumigations did not reduce the incidence of Verticillium wilt, and increased the yield of strawberries by a smaller factor than did the standard treatment using methyl bromide. Crop rotation by itself appears to have limited utility, except when used with other measures. Commercial strawberry cultivars showed different susceptibilities to Verticillium wilt, indicating that adoption of wilt-resistant cultivars will be necessary in some growing regions. Organic soil amendments incorporated prior to planting of strawberry plants produced varying degrees of control of Verticillium wilt. Additional investigation is necessary to refine proposed rates of amendment, demonstrate consistency over the range of environments and conditions under which strawberries are produced, and determine parameters of economic viability.

Measurements of the distribution of soil gas after application of Telone C35 (2,4-dichloropropene) by drip irrigation suggests that this method may result in lower emissions to the atmosphere than does shank injection.

Tests directly comparing application of alternate fumigants by drip or shanking methods show performance approximately equivalent to the present standard broadcast application of methyl bromide/chloropicrin, except for one main factor. The main alternatives tested have little or no activities as herbicides, leading to increased competition from weeds, and reduced yields of strawberries and increased costs of hand weeding. Additional work will be necessary to develop a replacement fumigant or treatment regimen producing the both biocidal and herbicidal effects necessary for economically viable strawberry farming given current technology.

Technical findings of the study have been communicated to growers and other stakeholders through an organized program of technical meetings/field days, and Methyl Bromide Alternatives tours. Among the other stakeholders are county extension agents, strawberry growers, *etc*.

## Executive Summary

California is first in strawberry production in the United States, producing 80% of fresh market strawberries. Strawberries are grown on roughly 24,000 acres per year in California, and have an estimated annual value of approximately 580 million dollars. The continued economic success of the strawberry industry in California will continue to rest, in part, on the industry's ability to develop a pest management program that balances cultural and biological control practices with chemical treatment.

For many years the strawberry industry has relied on both chemical treatments and cultural practices to diminish the impact of soil-borne diseases, insects, and weeds on the yield and quality of the fruit. In recent decades, the most important treatment has been methyl bromide, a broad-spectrum soil fumigant, applied in combination with chloropicrin. Preplant applications control most agronomically important diseases, prevent weed germination, and control arthropods present in the soil.

Methyl bromide has been identified, however, as having the potential to deplete the Earth's ozone layer, and for this reason its use is being phased out. Importation and domestic production of methyl bromide are to cease by the year 2001. At present no broad-spectrum soil fumigant that will replace methyl bromide is available to the strawberry industry.

Recognizing this problem, the California Strawberry Commission conducted a statewide, multi-faceted program during 1997-8 and 1998-9 to enable California's strawberry industry to rapidly identify and implement alternatives in managing soil-borne diseases. The research program used a unique alliance including experts from the California Strawberry Commission (CSC), the University of California (UC) and its Extension Service , the United States Department of Agriculture's Agricultural Research Service (USDA-ARS), the California Integrated Waste Management Board (IWMB), the California Department of Food and Agriculture (CDFA), and members of the crop protection industry.

The program successfully demonstrated that alternatives to the use of methyl bromide are technically feasible based on the studies conducted and their limitations. However, the economic viability of the tested alternatives to methyl bromide remains to be demonstrated. No tested alternative is an exact replacement for methyl bromide. Two main active ingredients tested, alone and together, provided reasonable control of wilt-producing soil microorganisms in small plot studies, but little control of weeds. On the whole, ozone and cultural practices, such as crop rotation and use of high-nitrogen soil amendments, appear to offer little promise as stand alone methyl bromide alternatives given current technology. Application of fumigants through systems of the type used in drip irrigation potentially offer reduced worker risk, reduced fumigant use, and the potential to stop or mitigate off-site movement. Additional trials are needed to fully delineate the constraints under which each alternative will perform satisfactorily and may be adopted. Simultaneous control of weeds and soil microorganisms, typical when methyl bromide is used, remains a goal that has not yet been realized.

The program described here had three major experimental components:

- Trials conducted at the Monterey Bay Academy during the 1998-98 and 1998-99 growing seasons, to evaluate a series of fumigation, barrier, microbial, soil gas, and cultural alternatives,

- Trials on a reduced-risk application of Telone C35, and
- On-farm trials conducted in 1998-99 on farms.

Discussions of the purpose, conduct, and outcome of each individual component are provided in separate sections below.

In addition the program had two further functions:

- Assembly of a compilation of pesticides currently used in growing strawberries in California. The document, titled A Crop Profile For Strawberries In California and issued in October, 1999, appears in Appendix A of this report.
- Dissemination of the study results, through organized outreach efforts. These included five technical meetings/field days and four Methyl Bromide Alternative tours, held throughout 1999-8 and 1999. Growers, regulators, researchers, and other stakeholders in the replacement of methyl bromide as a fumigant used in the strawberry industry participated. The technical meetings/field days are described in Appendix B, and the Methyl Bromide Alternative tours, Appendix C.

Finally, Appendix D lists the technical presentations and publications that resulted from the work carried out as part of the study.

## Section 1. Trials Conducted At The Monterey Bay Academy


### Summary

Tests of alternate bed fumigation treatments and techniques over a 2-year period showed that both shank injection and application *via* a drip system are superior to standard broadcast fumigation. For example, shank-injected methyl bromide/chloropicrin increased strawberry yield (relative to plants on untreated soil) by up to122%, and drip-applied Telone/chloropicrin by 134%. In these tests the standard broadcast treatment produced yield increases of 80 - 100%. Fumigation of beds using chemical alternates to methyl bromide appears feasible, but requires additional study and development.

A comparison of soil treatment by shank injection, drip application, and broadcast followed by mulching with VIF (virtually impermeable plastic film) confirmed the utility of the film in increasing yields and controlling wilt and root rot. Alternate treatments (chloropicrin alone, Telone/chloropicrin) were about as effective as methyl bromide/chloropicrin, suggesting that alternate fumigants and reduced application rates are possible, given additional evaluation.

Ozone, a potential replacement fumigant, increased the yield of strawberries by about the same amount as the standard methyl bromide/chloropicrin treatment in the first year of tests. Smaller and variable increases occurred in later tests. The technique is promising, and needs further study.

One-year crop rotations using rye or broccoli, and no fumigations, did not reduce the incidence of Verticillium wilt, but increased the yield of strawberries by about 40%, relative to untreated control, whereas standard fumigation increased yields by about 100%. Removal of strawberry debris decreased the incidence of wilt in subsequent crops, but had no effect on yield. Crop rotation by itself appears to have limited utility, except when used with other measures.

A weak and variable variety-specific inverse response appeared between strawberry yield and the level of Verticillium wilt organisms in the soil at planting. Yields from Selva variety strawberries did not vary appreciably with levels of the organism, whereas yields from Camarosa variety showed a slight negative correlation. Additional results confirm that Camarosa is least tolerant and Selva most tolerant to *Verticillium* spp, and that other varieties show variable susceptibility. Adoption of new cultivars, more tolerant to wilt, will be necessary.

Organic soil amendments incorporated prior to planting of strawberry plants produced varying degrees of control of Verticillium wilt. Blood meal, feather meal, and fish meal provided the best control, followed by chicken manure and compost. The amendments also caused phytotoxicity, however, and strawberry yields were only slightly improved relative to the control. Additional investigation appears necessary to refine proposed rates of amendment.


### Introduction

As discussed above, the strawberry industry in California currently relies heavily on use of methyl bromide to treat soil-borne diseases. Methyl bromide use is being phased out, and replacement treatments are needed. The California Strawberry Council is actively seeking alternatives. During the 1997-98 and 1998-99 season, a series of trials was conducted to evaluate a variety of potential replacements for methyl bromide. The following approaches were tested:

- Bed fumigation with chemical alternatives,
- Bed fumigation in conjunction with high-barrier film,
- Investigation of microbial mechanisms of fumigation response,
- Use of ozone gas as a soil fumigant, and
- Cultural practices.

## Materials and Methods

The experiments reported here were done in the 1997-98 and 1998-99 growing seasons at the Monterey Bay Academy (MBA), near Watsonville, CA. In addition, other demonstration plot sites were visited and some sampled for pathogens and/or other microorganisms. Appendix E contains maps of the Monterey Bay Academy trials.

In so far as possible, the experiments at MBA were done using normal grower practices for the region. With the one exception noted, all experiments had three or more replicates in blocked experimental designs appropriate for full statistical analyses of results. Ambient and soil physical conditions were monitored. The experiments included the following steps each year: ground preparation and flat fumigations of selected areas in early September; bed shaping on 52 inch centers, application of slow release fertilizer in bands under plant rows, installation of two drip tapes per bed, bed fumigations, and black plastic mulch installation in late September or early October; and transplanting strawberry runner plants (2 rows per bed with 14 inch spacing between plants) from high-elevation nurseries in mid-November. Transplants were subsampled and checked at the laboratory by standard isolation procedures for the presence of known pathogens (6, 7). With only a few exceptions, the incidence of transplants with *Verticillium dahliae* or *Phytophthora* spp. was less than 2%. Sprinkler irrigation was used for transplant establishment and drip irrigation for the remainder of the season. Aside from the soil and fumigation treatments given below for each experiment, normal best-management practices were used for plant diseases, insects, and mites.

Plant size was measured as the diameter of ground area covered by plants three times between February and June each year. Disease incidence was recorded at least monthly, and where needed, diagnosis of Verticillium wilt or Phytophthora root and crown rots was confirmed by isolations in the laboratory. Berries were picked twice weekly starting early April and ending late August. Berries from each plot were sorted for fresh market quality and culls, and each category weighed. Unless stated otherwise, above-ground crop residues were physically removed from the plots at the termination of the strawberry season in September. Beds were then knocked down and ground prepared for the next strawberry crop by normal practices.

## Bed Fumigation Experiments

Repeated fumigation treatments of the same ground with some of the chemical alternatives to methyl bromide were done as planned. A standard, embossed-black, polyethylene mulch was applied at the time of bed fumigation and left in place for the full growing season. All treatments were applied pre-plant. The following practices were tested:

- Methyl bromide/ chloropicrin (67/33% @ 325 lb/acre) applied by shank injection (Bed MeBr/Pic),
- Methyl bromide/ chloropicrin (67/33% @ 325 lb/acre) applied by broadcast shank injection (Flat MeBr/Pic),
- Telone/chloropicrin (65/35% @ 425 lb/acre) applied by shank injection (Bed Tel/Pic),
- Telone/chloropicrin (65/35% @ 425 lb/acre) applied through drip lines as an emulsion (Drip Tel/Pic),
- Chloropicrin alone (300 lb/acre) applied by shank injection (Pic), and
- Not treated (NT).

**High-Barrier Film/ Bed Fumigation Experiments**

In 1997-98, we compared a high-barrier or virtually impermeable plastic film ("VIF" Black Bromotech, Lawson Mardon Packaging, UK) with the standard embossed black plastic mulch using methyl bromide/chloropicrin, chloropicrin, and Telone/chloropicrin shank-injected at two rates, *i.e.*, those used in the Bed Fumigation Experiments and reduced by one third (10).

In cooperation with Drs. Ajwa and Trout, USDA-ARS, the effects of the high-barrier mulch, standard mulch, fumigant applications to beds in water emulsion through drip lines, and lower fumigant rates were tested during 1998-99 in a replicated field experiment on soil containing significant populations of *V. dahliae* and *Phytophthora* spp. (9).

**Microbial Mechanisms of Fumigation Response**

Since 1993, we have been researching microbiological differences associated with the enhanced growth and productivity of strawberries in fumigated soils where the major response is not due to control of known, major pathogens (10, 34, 35). Fumigated and nonfumigated strawberry beds at MBA and elsewhere were used during the 1997-98 and 1998-99 growing seasons to continue this research.

**Ozone Gas as a Soil Fumigant**

Although ozone in the upper stratosphere is at risk, in part due to methyl bromide, ozone itself may be an effective tool for soil treatment (25). Due to its reactivity, ozone is a very effective biocide and is used in a number of agricultural and food processing applications. It can be applied very safely and there is no residual activity or risk. Although ozone is much less active as a biocide in soil than is methyl bromide, ozone could possibly be used as part of integrated approaches to replace methyl bromide in certain soil applications. This possibility is being researched in cooperation with Alan Pryor of SoilZone, Inc., Davis, CA. (25).

Ozone is unstable and was generated on site. In November, 1997, after the beds were fully prepared and covered with polyethylene plastic mulch, ozone in air was injected at the rate of 400 lb/a through rigid drip-irrigation tubes buried 3.5-4.0 in. deep under the position of plant rows in the beds. Ozone applications were made with and without pre-inoculation with Bioworks T-22 (*Trichoderma harzianum*, Rootshield) granules applied in the plant rows at 100 lb/a. Strawberry runner plants were transplanted 5 days after ozone treatment. In early June, 1998, an additional application of 15 lb/a ozone was made to those ozonated plots that were previously inoculated with *Trichoderma*. A simultaneous, parallel experiment that included soil not-treated and soil fumigated by standard broadcast methods with methyl bromide/chloropicrin (Flat MeBr/Pic) was conducted for comparison purposes.

### Cultural Approaches for Management of Verticillium Wilt in Strawberry

*Verticillium dahliae* Kleb., the causal agent of Verticillium wilt on strawberry and many crops, is a soilborne pathogen with wide distribution in agricultural soils of California (13, 23, 28). The disease causes stunting, wilting, and collapse of plants, and therefore results in serious yield losses (1, 14, 29). Early this century and through the 1960s, Verticillium wilt was one of the most important constraints for strawberry production in California. Since 1960 soil fumigation with mixtures of methyl bromide and chloropicrin has been used to effectively control wilt on strawberry and fumigation has become an integral part of strawberry production in California (31). Methyl bromide has been identified as an ozone-depleting substance and will be banned in 2005. After the ban, Verticillium wilt will be one of the highest risk factors in strawberry production. Several chemical alternatives to methyl bromide can be effective, but one of the main ones, chloropicrin, does not control Verticillium as fully when used without methyl bromide. Therefore, we are researching several non-chemical or cultural approaches at the Monterey Bay Academy site that may be useful, either alone or in combination with other measures, for management of Verticillium wilt in the longer term.

### Cultural Approach - Crop Rotations

Two phases of an experiment on a broccoli-strawberry rotation on nonfumigated soil were completed during the grant period. The ground used was cropped uniformly with strawberries without fumigation in the preceding year. In 1996-97, the rotation treatments were done as follows: Selva strawberry with all residues incorporated; Selva strawberry with above-ground residues physically removed at end of season; two consecutive crops of broccoli with all residues incorporated; and a cover crop of rye mowed to 6-8 in and finally incorporated. In 1997-98, all plots were planted with Selva strawberry to measure disease progress and yield (10).

### Cultural Approach - Inoculum Thresholds for Verticillium Wilt of Strawberry

Understanding thresholds for economic losses caused by Verticillium wilt will enhance future cultivar deployment and will allow a risk assessment based on pre-plant soil assays (13, 14, 23, 24). We completed several greenhouse and two field experiments on inoculum thresholds, and a third field experiment is in progress. The field experiments were done as proposed. The plots were initially bed-fumigated with methyl bromide/chloropicrin, 67/33%, at 325 lb/acre. Treatments included five inoculum densities, the varieties Camarosa and Selva, and were arranged in a split-plot design with three replications in which inoculum density was the main plot and variety the sub-plot. Soil naturally infested with about 50 micro sclerotia of *V. dahliae* per gram (50 ms/g) was used as inoculum. Various proportions of infested soil were added to the corresponding main plots to establish different inoculum levels, with the same volume of fumigated soil removed from the bed before hand. Beds were then rototilled, reshaped, bands of slow-release fertilizer applied, drip irrigation installed, and covered by plastic. Soils were sampled at planting and periodically during the season to quantify the inoculum densities (24).

A repeat experiment is in place for 1999-2000 with approximately 0.5, 2, 5, 10, and 30 ms/g soil at planting. One of the differences between the field experiments done in 1997-98 and 1998-99 is that soil in beds was not mixed as well or as deeply in 1998-99 because of machinery problems. Extra care was taken in mixing, rototilling, and reshaping the beds for the current 1999-2000 experiment. Growth, yields, and symptoms will be measured weekly. Preliminary counts indicate that we did obtain the desired range of initial inoculum levels.

**Cultural Approach - Variety Susceptibility to Verticillium Wilt**

To gain additional information on the relative susceptibility of California cultivars (1, 27, 33), three to six different cultivars were grown on the same non-fumigated soil each year between 1995 and 1999. There were four to seven replicate plots for each variety, depending on the year.

**Cultural Approach - Influence of High-Nitrogen Organic Amendments on Verticillium Wilt**

Various organic materials such as manures, sewage sludge, food processing wastes, and composts have been researched for their potential disease suppressive effects when incorporated into soils (2, 5, 11, 12, 15, 17, 26, 29). More specifically, others have found additions of high-nitrogen organic amendments to reduce populations of *V. dahliae* in soil and the incidence of Verticillium wilt in potato (3, 18). Furthermore, these effects lasted for more than one year following treatment. Therefore, selected high-nitrogen organic amendments were tested further for their activity in reducing Verticillium wilt in strawberry (30).

As proposed, prospective soil amendments were initially tested in the greenhouse for phytotoxicity. Amendments tested included blood, bone, and fish meal, each at 2%, 1%, and 0.2% by weight, and chicken manure, both fresh and composted, at 2% by weight. Amendments were incorporated into a mixture of 1 part natural field soil and 2 parts potting soil, brought to field capacity, and held for 6 weeks before transplanting Camarosa runner plants. The activity and phytotoxicity of these and other soil amendments reported to reduce Verticillium wilt in other systems is being researched further in the greenhouse.

High-nitrogen organic amendments were used in a field experiment starting September, 1998. Nonfumigated ground was prepared and listed into three beds. Treatments were assigned to 50-ft X 1-bed units by a randomized complete block design and amendments incorporated to a depth of 30 cm. Beds were then reshaped by machine, covered with plastic mulch, and irrigated by drip lines. Slow-release fertilizer was applied only to the non-treated and compost plots. Plant holes (10 cm diam.) were then cut 4 weeks and Camarosa transplanted 7 weeks after amendment incorporation. Blood, feather, and fish meal were applied at 8, 4, and 8 tons/acre bed treated area, respectively.

This field experiment on soil amendments is being repeated starting September, 1999, with a substitution of blood meal at a lower rate for chicken manure. In cooperation with Coastal Berry, a new 0.3 acre experiment was initiated September, 1999, on new ground at the Monterey Bay Academy near Watsonville. The field is being grown organically and contains significant populations of *V. dahliae*. The field was divided into 3 replicate blocks, 12 units each containing blood, feather, or fish meal at rates between 0-6 tons/acre. Soil was prepared, amendments added and incorporated on the flat, and sprinkler irrigated. Beds were made later and planted with Aromas by normal practice. Pathogen populations, strawberry growth and yield, and disease development are being measured as before. These experiments should provide valuable information on rates of soil amendments and conditions that reduce Verticillium wilt and avoid phytotoxicity. The amendments used, or cheaper versions thereof, are potentially available in processed forms that should be pathogen free, but that will be verified and appropriate information on any perceived or real human health risks provided with the final results.

## Results

### Bed Fumigation Experiments

At MBA, where *Verticillium dahliae* is present, all of the bed fumigation treatments used in several years of experiments increased yield significantly relative to that on nonfumigated soil (8-10). For example, with shank-injected rates given per unit bed area actually treated (58% of total area), the increases in yield for 1998 were 122% for methyl bromide/chloropicrin (67/33% @ 325 lb/acre), 71% for chloropicrin alone (300 lb/acre), and 95% for Telone/chloropicrin (65/35% @ 425 lb/acre) (Figure 1). Application of the Telone/ chloropicrin mixture at the same rate in a water emulsion through drip lines increased yield 134%, while the standard method of broadcast fumigation with methyl bromide/chloropicrin (67/33%, 325 lb/acre total area) increased yield 107% relative to that obtained on nontreated soil (Figure 1). The increases in yield relative to nontreated soil in 1999 for bed fumigation by shank injection were 100% for methyl bromide/chloropicrin (67/33% @325 lb/a) and 96% for chloropicrin alone (300 lb/a) (Figure 2). Standard broadcast fumigation with methyl bromide/chloropicrin increased yield 80% (Figure 2). (Telone/chloropicrin was not reapplied in this experiment for 1998-99.) Fumigation treatments generally increased plant size 40-50% and these increases were always significant (9, 10). All fumigation treatments reduced *V. dahliae* populations in soil and effectively controlled weed growth through plant holes in the plastic mulch. The results show that bed fumigations with the materials used can be effective, but further research is needed to optimize specific methods of application. We are currently (1999-2000) repeating aspects of the bed fumigation experiment above with methyl bromide and chloropicrin, and sampling plants, roots, and soil to continue investigations of microbial mechanisms of fumigation responses in strawberry (9, 10, 34, 35).

### High-Barrier Film/ Bed Fumigation Experiments

In the 1997-98 tests, the high-barrier mulch increased yield in every treatment and the highest yield was obtained with high-barrier mulch and Telone/ chloropicrin at 283 lb/a bed-treated area (164 lb/a total area) (Figure 3). However, this was the only experiment not to be replicated fully and the only significant result was that the high-barrier mulch increased yield over that obtained with standard mulch by an average 16% across all chemical treatments.

In the 1998-99 tests, shank fumigation of beds with methyl bromide/chloropicrin and VIF mulch increased berry yields 4.5 fold relative to nontreated soil, and methyl bromide/chloropicrin with standard mulch was only slightly less effective (Figure 4). Shank applied chloropicrin at 200 and 300 lb/acre gave yields nearly equivalent to those obtained with methyl bromide/chloropicrin, but drip-applied chloropicrin at 180 lb/acre was somewhat less effective; VIF mulch did not improve yields in the chloropicrin treatments (Figure 4). Results with Telone/chloropicrin (C35) were more variable, but shank applications to beds at 283 and 425 lb/acre with standard mulch gave yields nearly equivalent to methyl bromide/ chloropicrin, and there was no benefit of VIF in these treatments. Drip applications of Telone/chloropicrin were slightly less effective, but VIF mulch improved yields with drip-applied Telone/chloropicrin (Figure 4). It should be noted that the actual rates of active ingredients applied by drip turned out to be somewhat lower than those applied by shank. The results from 1998-99 differ somewhat from those obtained in 1997-98 when VIF mulch improved yields significantly in a variety of shank-applied bed fumigation treatments. Disease incidence was variable in this experiment, but both Verticillium wilt and Phytophthora root rot were controlled adequately in most treatments. All fumigation treatments effectively increased plant growth and controlled weed growth through plant holes in the plastic mulch. The results show that bed fumigations with the materials and methods used can be effective in the presence of significant disease pressures from soilborne pathogens, and the drip-emulsion method of soil fumigation shows good promise. It may also be possible to use fumigants effectively at reduced rates, but the specific rates and methods of application need further research to be optimized.

**Investigation of Microbial Mechanisms of Fumigation Response**

So far, plants in fumigated soils consistently have much higher root length densities and fewer dark roots than plants in nonfumigated soils. Species of fungi that we find to be damaging to strawberry roots (e.g., *Cylindrocarpon*, *Pythium*, and *Rhizoctonia* species) are isolated significantly less often from roots in fumigated than in nonfumigated soils (32, 35). Populations of fluorescent pseudomonads in soil, however, are increased significantly10 days to 9 months after fumigation. Predominant isolates of fluorescent pseudomonads from the rhizosphere were tested for effects on strawberry root growth and health in natural field soils in the greenhouse. The effects of individual isolates ranged from beneficial to deleterious, but several isolates of *Pseudomonas fluorescens*, *P. putida* and *P. chlororaphis* from strawberry rhizospheres in fumigated soils were beneficial (34). The results suggest that reductions in deleterious fungi and increases in beneficial bacteria contribute to the general growth response of strawberry to soil fumigation (10, 19, 20, 21, 34, 35, 37). This hypothesis is being researched further because knowledge of mechanisms underlying strawberry responses to fumigation will aid development of future alternatives to methyl bromide, including possible biological and cultural controls (4, 21).

**Ozone Gas as a Soil Fumigant**

The total yields of marketable berries for the 1997-98 ozone experiment are shown in Figure 5. The yields of a simultaneous and nearby experiment with nonfumigated soil and a standard broadcast application of methyl bromide/chloropicrin are also shown for comparison in Figure 5. Ozone with *Trichoderma* added increased yield significantly over that obtained with either ozone or *Trichoderma* alone and gave a total yield almost equivalent to that obtained in a parallel experiment with methyl bromide/chloropicrin (25).

These results were very encouraging and a repeat experiment was done in 1998-99. This experiment was performed at the same site and in nearly the same manner as the one above. The differences included burying the drip tubing 6 in. deep and the added treatments listed in Table 1 below. The increase in yield resulting from each ozone treatment compared to untreated soil is shown in Table 1 (25).

We do not know the reasons ozone with *Trichoderma* added gave a less than significant yield increase in 1999 but gave a much larger and significant increase in 1998. The overall yields in 1999, however, were much higher, probably because of less soilborne disease pressure throughout the 1998-99 ozone experiment (25). Furthermore, because of leakage at some above-ground fittings, mid-season applications of ozone in 1999 caused some phytotoxicity to leaves. We are currently repeating experiments with ozone at the Monterey Bay Academy on ground with significant disease pressures.

**Table 1. Effect of Fumigation with Ozone**

Increases or decreases in the 1999 yield of marketable strawberries, relative to an untreated control, due to various pre-plant and mid-season treatments of soil with ozone with or without *Trichoderma harzianum* (T-22) added.

| Pre-plant Treatments | Mid-season treatments | Relative marketable yield (%) |
|---|---|---|
| 400 lb/a Ozone + T-22 | None | +11.3 |
| 100 lb/a Ozone + T-22 | 3 X 5-15 lb/a Ozone | +9.7 |
| 400 lb/a Ozone | None | +6.1 |
| None | None | 0.0 |
| 400 lb/a Ozone + T-22 | 3 X 5-15 lb/a Ozone | -6.0 |
| 100 lb/a Ozone | 3 X 5-15 lb/a Ozone | -6.5 |

## Cultural Approach - Crop Rotations

None of the 1-year rotations out of strawberry reduced the incidence of Verticillium wilt in strawberry during 1998 (Figure 6). In fact, the only treatment that reduced Verticillium wilt significantly was the physical removal of strawberry residues from the preceding strawberry crop. Nevertheless, a one-year rotation with broccoli or rye increased subsequent strawberry yields by nearly 40%, relative to continuous strawberry, all on nonfumigated soil, and these effects were highly significant (Figure 7). Removal of all strawberry debris between consecutive crops of strawberry did not increase yield significantly. In a parallel experiment on neighboring ground, standard fumigation with methyl bromide/chloropicrin approximately doubled yields (Figure 7).

Others have reported broccoli rotations to reduce Verticillium wilt in cauliflower and other rotations to reduce Verticillium wilt in potato (5, 16, 22, 23, 28, 36). We do not know why the broccoli rotation was not more beneficial here. In comparison to fumigation, the beneficial effects of 1-year rotation out of strawberry were small (Figure 7). Nevertheless, crop rotations, especially when combined with other methods, may be helpful in certain situations where fumigation is less effective or less available than now (29). We are continuing crop rotation experiments at the Monterey Bay Academy.

## Cultural Approach - Inoculum Thresholds for Verticillium Wilt of Strawberry

In greenhouse experiments, the incidence of plants with symptoms 3 months after inoculation increased linearly with inoculum level in both Selva and Camarosa, but the slope of the relationship of disease to inoculum was significantly lower for Selva (10).

As expected, inoculum thresholds for disease symptoms were significantly lower for Camarosa than for Selva. However, while we found clear relationships between initial inoculum levels at planting and disease development in 1998 (Figure 8), this was not the case in 1999 (9, 10). In fact, for Selva, there was no relationship between inoculum levels measured in soil and disease in 1998-99, and there was only a barely significant relationship for Camarosa. Nevertheless, the effect of initial inoculum on the total yield of Camarosa in 1999 was significant, e.g., inoculum levels higher than 2 ms/g soil reduced yield significantly (Figure 9).

**Cultural Approach - Variety Susceptibility to Verticillium Wilt**

The final mean incidence of plants with visible symptoms of Verticillium wilt in each of 4 years is shown in Figure 10. Camarosa was consistently the most susceptible and Selva was relatively tolerant. Unfortunately, the relative susceptibility of other varieties (e.g., Laguna, Seascape, and Diamante) varied between years. This suggests that there are strong genotype-by-climate interactions affecting the development of Verticillium wilt in strawberry. Although they may be difficult to obtain, cultivars well adapted to California conditions with greater tolerance to Verticillium wilt will be needed.

**Cultural Approach - High-Nitrogen Organic Amendments and Verticillium Wilt**

In the greenhouse tests, blood, bone, and fish meal all had residual phytotoxicity at 2% by weight, but were only slightly toxic at 1%, and did no damage at 0.2%. Chicken manure, both fresh and composted, had a slight residual phytotoxicity only at 2%. Blood, bone, and fish meal at >1% reduced *V. dahliae* populations in soil to undetectable levels. Furthermore, residual phytotoxicity varied greatly with soil moisture. The activity and phytotoxicity of these and other soil amendments reported to reduce Verticillium wilt in other systems is being researched further in the greenhouse.

In the field experiment, blood, feather, and fish meal, applied at 8, 4, and 8 tons/acre bed treated area, respectively, all reduced pathogen populations and the incidence of Verticillium wilt in Camarosa significantly during 1999 (Figure 11) (9). Table 2 shows opulations of *Verticillium dahliae* in field soil before organic amendments were incorporated and 7 weeks later at the time Camarosa strawberry was planted.

**Table 2. Effect of Organic Soil Amendments on Soil Populations of *V. dahliae***

| | Microsclerotia/g soil | |
|---|---|---|
| Amendment | Before treatment | After treatment |
| None | 35 | 46 |
| Compost | 21 | 38 |
| Chicken Manure | 26 | 16 |
| Fish Meal | 25 | 0.5 |
| Feather Meal | 23 | 0 |
| Blood Meal | 26 | 0 |

However, the organic amendments used also caused phytotoxicity and, therefore, did not give increases in yield proportional to levels of disease reduction (Figure 12) (9). Chicken manure and mature compost (8 and 12 tons/acre, respectively) did not reduce Verticillium wilt significantly. Major transitions in soil microbiology, ammonia, and pH occurred as expected following additions of high nitrogen amendments (3, 18).

## 1998 CumulativeYield of Marketable Berries

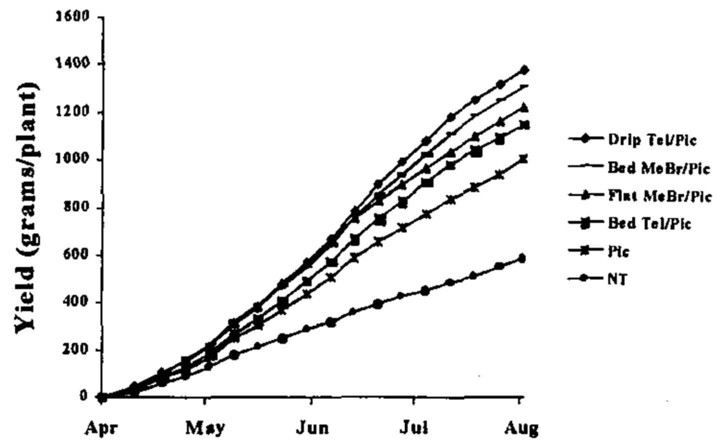



**Figure 1. Yields Following Use of Various Fumigants - 1998**

Cumulative yields of marketable Selva strawberries grown in 1997-98 on soil subjected to the following pre-plant fumigation treatments: Telone/chloropicrin applied to beds through drip lines as an emulsion (Drip Tel/Pic); shank injection of beds with methyl bromide/ chloropicrin (Bed MeBr/Pic); broadcast shank injection with methyl bromide/ chloropicrin (Flat MeBr/Pic); shank injection of beds with Telone/chloropicrin (Bed Tel/Pic); shank injection of beds with chloropicrin alone (Pic); and not treated (NT). See text for rates and ratios of chemicals applied. All of the fumigation treatments increased yield significantly, and chloropicrin alone worked significantly less well than drip applied Telone/chloropicrin or bed fumigation with methyl bromide/chloropicrin.

## 1999 Cumulative Yield of Marketable Berries

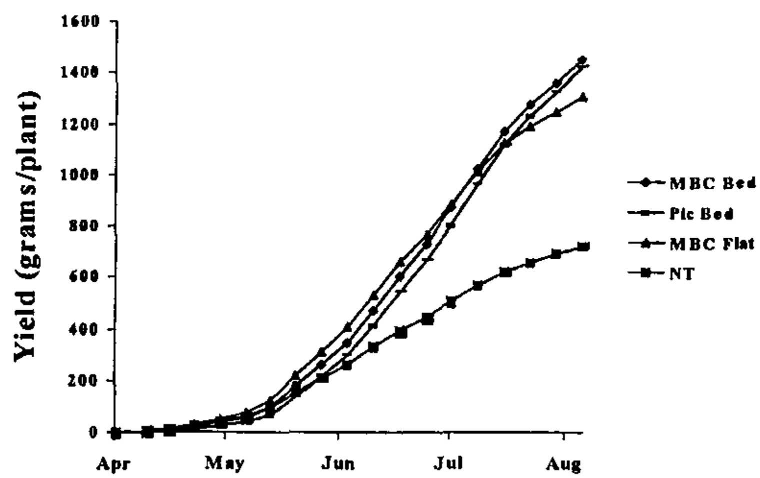



**Figure 2. Yields Following Use of Various Fumigants - 1999**

Cumulative yields of marketable Selva strawberries grown in 1998-99 on soil subjected to the following pre-plant fumigation treatments: shank injection of beds with methyl bromide/chloropicrin (MBC Bed); shank injection of beds with chloropicrin alone (Pic Bed); broadcast shank injection with methyl bromide/chloropicrin (MBC Flat); and not treated (NT). See text for rates and ratios of chemicals applied. All of the fumigation treatments increased yield significantly but did not differ significantly from each other.

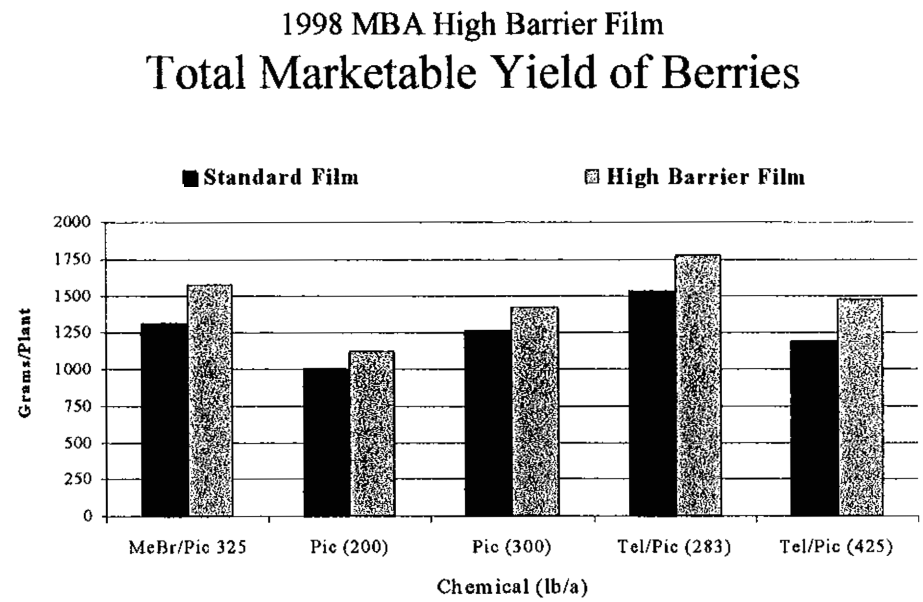



**Figure 3. Yields Using Different Mulches and Fumigants**

Total yields of marketable Selva strawberries grown in 1997-98 on soil bed fumigated by shank injection with methyl bromide/chloropicrin (MeBr/Pic) at 325 lb/a, chloropicrin (Pic) at 200 or 300 lb/a, and Telone/chloropicrin (Tel/Pic) at 283 or 425 lb/a. Black bars represent standard embossed polyethylene mulch and gray bars represent VIF or high barrier plastic mulch. Plastic mulches were applied at or before the time of fumigation and remained in place throughout the growing season. Chemical rates given per bed treated area which was 58% of the total area.

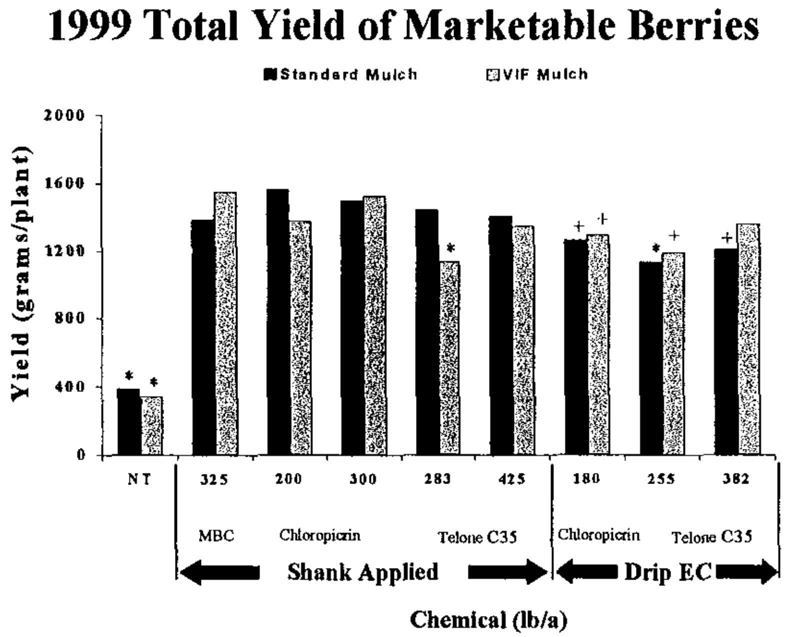



**Figure 4. Comparison of Yields After Application by Shank and Drip Methods**

Total yields of marketable Selva strawberries grown in 1998-99 on beds fumigated by shank injection (Shank Applied) with methyl bromide/chloropicrin (MBC) at 325 lb/a, chloropicrin at 200 or 300 lb/a, and Telone/chloropicrin (C35) at 283 or 425 lb/a; or on beds treated by drip emulsion application (Drip EC) of chloropicrin at 180 lb/a, and Telone/chloropicrin (C35) at 255 or 382 lb/a. Black bars represent standard embossed polyethylene mulch and gray bars represent VIF or high barrier plastic mulch. Plastic mulches were applied at or before the time of fumigation and remained in place throughout the growing season. An asterisk (*) indicates that the yield was significantly less than that obtained with methyl bromide/chloropicrin and standard mulch, and a plus (+) indicates that the yield was significantly less than the two highest yielding treatments. Chemical rates given per bed treated area which was 58% of the total area.

1998 MBA Ozone Treatments

Total Marketable Yield of Berries

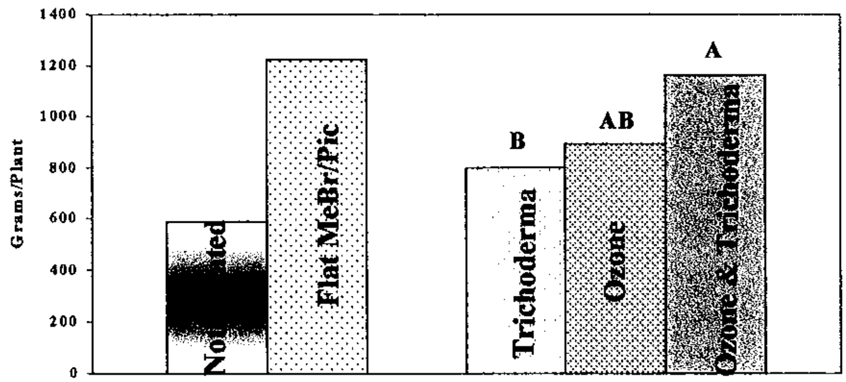



**Figure 5. Yields After Fumigation with Ozone**

Total yields of marketable Selva strawberries for the 1997-98 ozone experiment and for a simultaneous, parallel experiment that included soil not-treated and soil fumigated by standard broadcast methods with methyl bromide/chloropicrin (Flat MeBr/Pic). Treatments indicated on the bars are described fully in the text. Yields for the ozone experiment with different letters differ significantly.

## 1998 MBA Rotation
# Disease Incidence

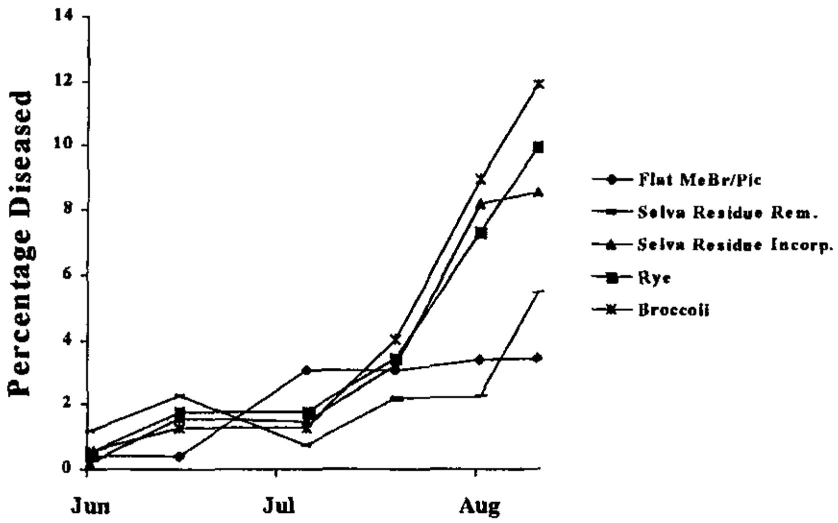



**Figure 6. Effect of Crop Rotation on Incidence of Verticillium Wilt**

Incidence of Selva strawberry plants with visible symptoms of Verticillium wilt plotted as a function of time during the 1998 growing season. Data points are means of three replicate plots that were not fumigated and had the rotation crop indicated in the preceding year. Data from soil broadcast fumigated with methyl bromide/chloropicrin (Flat MeBr/Pic) in a nearby experiment are also shown for comparison.

1998 MBA Rotation Treatments

**Total Marketable Yield**

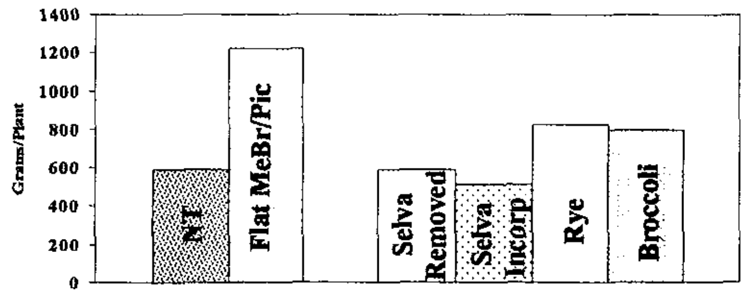



**Figure 7. Effect of Crop Rotation on Yield**

Total yields of marketable Selva strawberries for the 1997-98 rotation experiment and for a simultaneous, parallel experiment that included non-treated soil (NT) and soil fumigated by standard broadcast methods with methyl bromide/chloropicrin (Flat MeBr/Pic). Treatments indicated on the bars are described fully in the text. Both 1-year rotations out of strawberry on non-fumigated soil increased yield significantly.

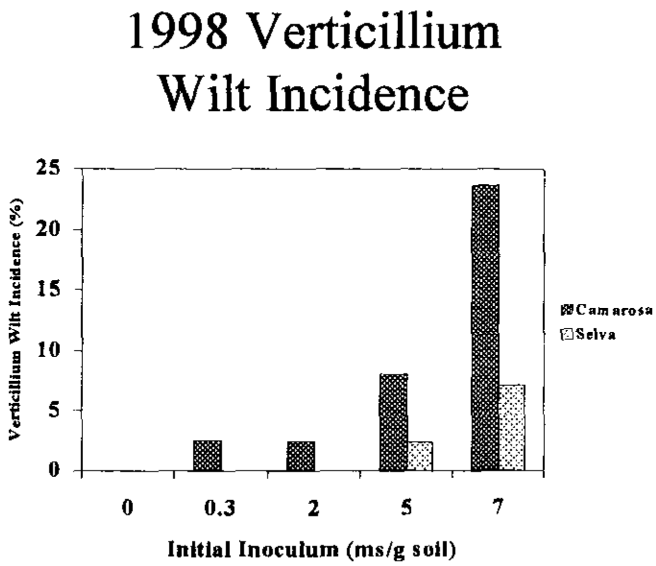



**Figure 8. Dependence of Wilt Incidence on Wilt Organism Level at Planting**

Final incidence of Camarosa (black bars) and Selva (gray bars) strawberry plants with visible symptoms of Verticillium wilt in 1998 plotted as a function of inoculum levels measured in soil at the time of planting in November, 1997. Different levels of initial inoculum were obtained by mixing various amounts of non-fumigated soil containing a natural population of *V. dahliae* with fumigated soil in the beds 2-3 weeks before planting. Final disease incidence was measured in late August, 1998.

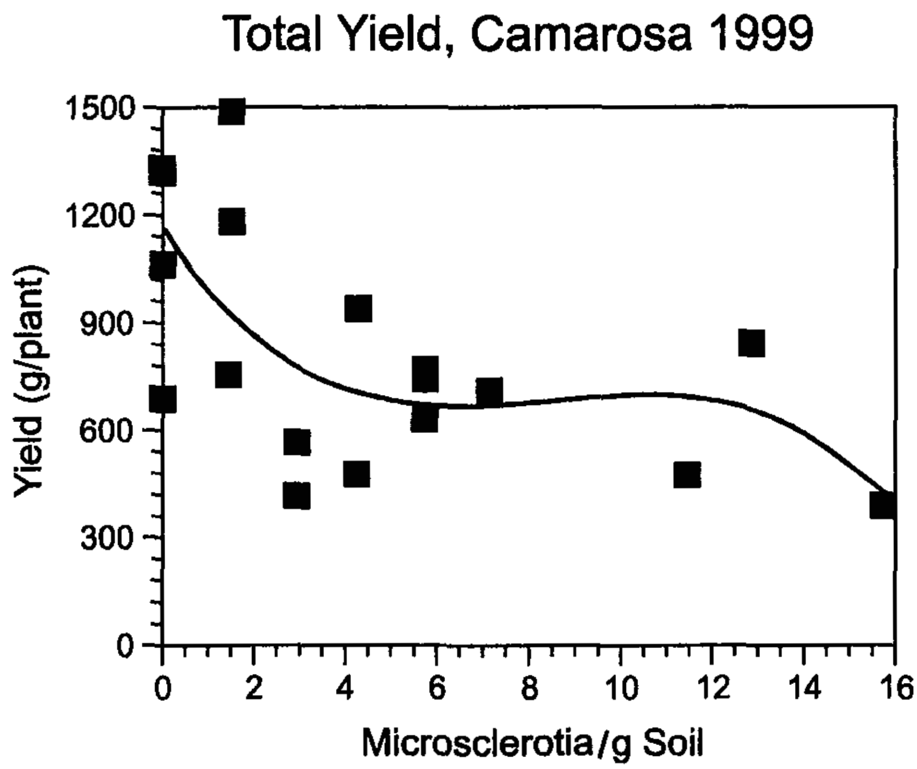



**Figure 9. Relationship between Yield and Wilt Organism Level at Planting**

Total yields of marketable Camarosa strawberries for 1999 plotted as a function of the number of *Verticillium dahliae* microsclerotia per gram soil measured at planting in November, 1998. Different levels of initial inoculum were obtained by mixing various amounts of nonfumigated soil containing a natural population of *V. dahliae* with fumigated soil in the beds 2-3 weeks before planting.

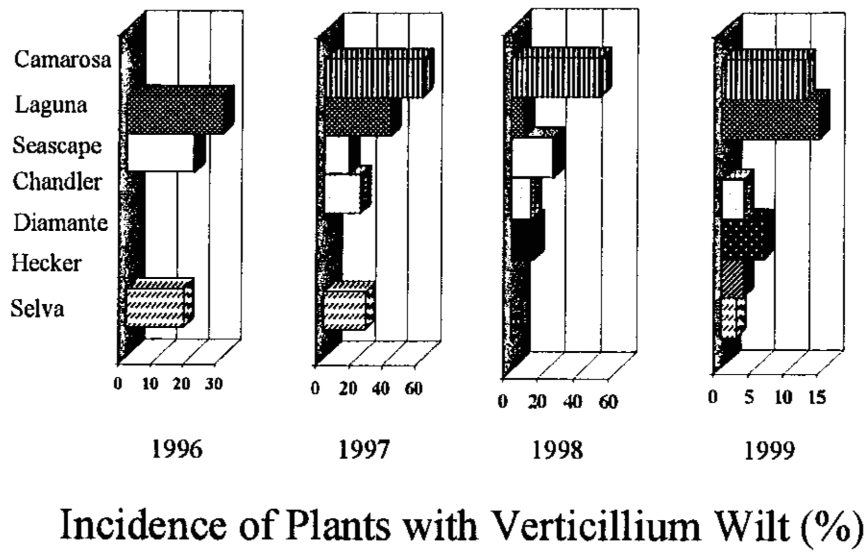



**Figure 10. Correlation of Cultivar Type with Incidence of Verticillium Wilt**

Final incidence of strawberry plants with symptoms of Verticillium wilt each year 1996-99. Three to six cultivars were grown each year in replicated plots on the same non-fumigated soil containing natural populations of *V. dahliae*. Final disease incidence was measured in late August.

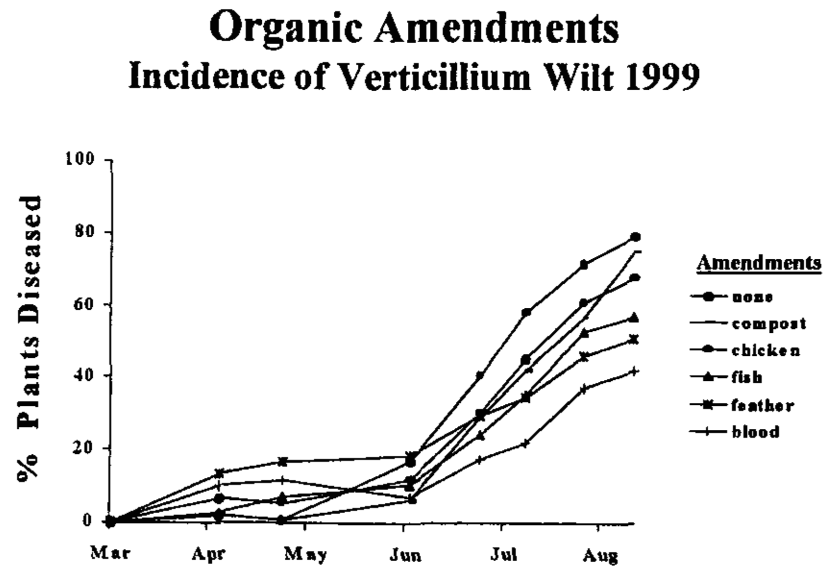



**Figure 11. Incidence of Verticillium Wilt Using Organic Soil Amendments**

Incidence of Camarosa strawberry plants with visible symptoms of *Verticillium* wilt plotted as a function of time during the 1999 growing season. Data points are means of three replicate plots containing one of the organic amendments listed.

# Organic Amendments
# 1999 Total Yield of Marketable Berries

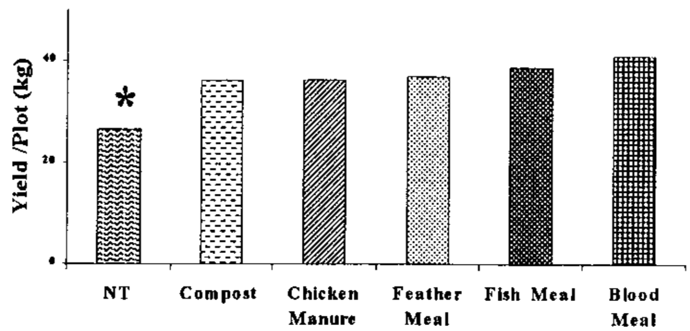



**Figure 12. Effect of Organic Soil Amendments on Yield - 1999**

Total yields of marketable Camarosa strawberries obtained in 1999 per plot where nonfumigated soil was treated before planting with the organic amendments listed. Each bar is the mean of three replicate plots and the asterisk (*) indicates a significant difference from other treatments.

## Section 2. Evaluation of a Reduced Risk Application Method


### Summary

Application of a soluble formulation of Telone C35 (INLINE®, active ingredient 1,3-dichloropropene, or 1,3-D) through drip irrigation system to raised beds may reduce the amount applied without sacrificing its efficacy to control soil-borne pathogens. This study suggest that a minimum of 25 mm (~ 1 in.) of water is needed to deliver chemicals to the edge of raised beds (76 cm. or ~ 30 in. wide). The greatest distribution uniformity of fumigants across the bed was obtained with 35 mm of irrigation water. The soil gas distribution data suggests that drip application of fumigants may result in lower atmospheric emission than shank injection.


### Introduction

The application technique used to deliver fumigants to the soil is a major factor in determining efficacy and emissions. Research on application of emulsified Telone C35 formulation (INLINE®, active ingredient 1,3-dichloropropene) through drip irrigation systems showed that this method is very effective in controlling soil pathogenic fungi and parasitic nematodes. One potential advantages of the drip application method over standard shank fumigation is that no workers are required to be in the field during fumigation. The plastic tarp that is used with, and disposed following, standard flat fumigation (about 1000 lb/ac) is not needed. The drip tubing is used for both chemical application and crop irrigation.

Over the past two years, the Water Management Research Laboratory, in cooperation with the California Strawberry Commission (CSC), researchers from the University of California (UC), and chemical manufacturers, have adapted and evaluated drip application methods to apply 1,3-D and chloropicrin for strawberry production. Our research has shown that drip-applied INLINE can produce yields nearly equal to those with methyl bromide fumigation (38) and reduced rates are possible if soil conditions and application methods are correct.

Because the concentration of chemicals in the irrigation water varies with amount of irrigation water, this research was designed to determine the distribution of 1,3-D in the soil profile after the drip-application of INLINE in various amounts of irrigation water to raised soil beds covered with standard plastic and virtually impermeable film.

### Materials and Methods

Innovative techniques were developed and used to evaluate the distribution of fumigants in soil by direct, real-time measurements of soil concentrations of 1,3-D (39). A field-gas chromatograph (P200H Portable GC, MTI Analytical Instruments, Fremont, California) was used to measure 1,3-D concentration in the soil gas at levels greater than 100 ug $L^{-1}$. Charcoal traps (ORBO-32) were used to collect gas samples at lower concentrations.

Water-soluble formulation of Telone C35 (INLINE) was injected into raised soil beds (76 cm wide) with irrigation water through 2 drip-lines irrigation system. Positive displacement pumps (Inject-o-meter, Clovis, New Mexico) or pressurized cylinders containing the emulsified fumigant were used to inject the fumigant into the irrigation system.

After fumigation, soil gas samples were collected immediately under the plastic cover and at various depths (10, 20, 40, and 60 cm) using stainless steel tubes. Soil distribution of 1,3-D was determined under standard plastic and virtually impermeable film (VIF). Soil gas distribution was also determined for one drip application rate in three amounts of irrigation water (15, 25, and 35 mm) applied to beds covered with standard plastic film.

**Results**

The concentrations of 1,3-D and in the soil gas were greatest after 24 to 36 hrs following application, regardless of the application method. However, 1,3-D volatilized more slowly from the water-applied formulation than after shank fumigation. The measured concentration of 1,3-D immediately under standard film after 24 hours following fumigant application was 3 to 4 times greater in the drip applied treatments than under shank injection treatments. Also, the concentration of 1,3-D was 11 times greater under VIF than under standard film.

This study found that distribution uniformity of fumigants across the bed increases with increasing the amount of water used to deliver the fumigants. For the same application rate of INLINE, higher amounts of irrigation water resulted in higher soil gas concentrations at depths below 10 cm, possibly because water acted as a barrier that reduced 1,3-D dissipation into the atmosphere.

Only trace concentrations of fumigants were detected in the soil gas at depths below 60 cm. After 14 days following application, 1,3-D concentrations in the soil gas at any depth were very small (less than 10 ng/mL).

## Section 3. Cooperative On-Farm MeBr Alternatives Trials 1998-1999


### Summary

Tests comparing application of alternate fumigants (primarily 1,3-dichloropropene and chloropicrin) applied by drip or shanking methods show performance approximately equivalent to the present standard broadcast applicaton of methyl bromide/chloropicrin, but with one major tradeoff. In trials in six different coastal areas, strawberry yields close to those from standard applications were observed, but with much greater weed pressure because the alternatives (except for metam-sodium) have little or no activities as herbicides. Decreased yields occurred at one trial in the central valley, where weeds are the primary competition. No marked correlation could be seen between yield and the type of tarp (mulch) used, although using a clear tarp in some cases led to increased weed pressure.

Use of alternative fumigants in combination with tarps to reduce potential emissions and enhance fumigant effectiveness appears to have a potential detrimental phytotoxic effect. Determining the appropriate interval between fumigation and planting will be critical to successful use of alternatives to methyl bromide.

Absence of herbicidal activity in the fumigant leads to increased costs for maintenance weeding, in order to preserve yield. Additional work with metam-sodium or other herbicides will be necessary to develop a replacement fumigant with the necessary biocidal and herbicidal properties.


### Introduction

With the loss of methyl bromide a different strawberry cropping system that encompasses both strawberry nursery and fruit production will have to be developed. Thus far there has been little headway made to this end in the nurseries given the constraints in that production setting. With respect to fruit production, a cropping system based on existing integrated pest management practices is being developed. A potential key component of this new cropping system is the application of materials through the drip irrigation system to control soil-borne pests. Application of materials through the drip irrigation system provides an opportunity to deliver key pesticides required for economic strawberry farming in a reduced risk (to the environment, worker and off site exposure potential) formulation and manner. Preliminary trial data looks promising, yet considerable obstacles still need to be resolved with respect to the logistics of farming with methyl bromide alternatives (ex. plant back requirement), fumigant rates required to control key pests with a given tarp class, combinations of fumigants/other pesticides required for economic strawberry production, weed control, VIF tarp quality, price, and commercial availability, economics, and regulatory issues.

A major problem of testing methyl bromide alternatives is the fact that nearly all ground available to test methyl bromide alternatives has been fumigated with methyl bromide for a number of years. The result of this is that yields from methyl bromide alternatives produce yields comparable to current fumigation practices. Unpublished data (K.D. Larson, Department of Pomology, University of California, Davis) from research station trials conducted over a number of years suggests a gradual decline in productivity under methyl bromide alternatives.

Chloropicrin, Telone C35, and metam sodium are currently registered materials that can play a role in a methyl bromide alternatives *program*. In general, these materials are not extensively used alone at this time at the rates that would be required in strawberry production due to either one or more of the following relative to current common preplant soil fumigation practices: lack of control of a key pest, cost, regulatory limitations, lack of technology to uniformly apply material for consistent production, plant back requirement too long. Research is underway to address some of these limitations.

With respect to drip irrigation-applied methyl bromide alternatives, California Strawberry Commission on-farm field trials (partially funded by the California Department of Pesticide Regulation Pest Management Alliance Program and the USDA ARS) in the 1998-1999 cropping year had 2.9 acres under drip irrigation-applied methyl bromide alternatives. Due to farmer interest in the trials established in the 1998-1999 cropping year, approximately 20 acres of drip applied methyl bromide alternatives have been established for the 1999-2000 cropping season. The acreage under drip applied methyl bromide alternatives in the 1999-2000 season is a 700% increase over that in the 1998-1999 season.

## Materials and Methods

For the 1998-1999 growing season seven on-farm methyl bromide alternative trials in strawberry were established. There was at least one trial in each growing district (see Table 3). General treatments at each coastal site are presented in Table 4. The following are descriptions of the location and goals of the trials at each site.

### Watsonville, Site #1

This is a northern coastal California location using the northern California production system with a variety that is adapted to both northern and southern California. The goal at this site was to compare the efficacy of bed-applied MeBr alternatives applied by drip irrigation and shank application vs. the standard shank application containing MeBr. *Soil fumigants applied by drip irrigation are a reduced risk emissions means of preplant soil fumigation, and have the potential to be a reduced emissions means of preplant soil fumigation.* In addition, VIF (Virtually Impermeable Film) in conjunction with MeBr alternatives were investigated as a means to further reduce potential emissions and risk of soil fumigants and enhance fumigant effectiveness.

### Watsonville, Site #2

This is a northern coastal California location using the northern California production system with a variety that is adapted to both northern and southern California. The goal at this site was to compare the efficacy of bed-applied MeBr alternatives applied by drip irrigation vs. the standard shank application containing MeBr. In addition to the above, VIF was investigated as a means to further reduce potential emissions and risk of soil fumigants and enhance fumigant effectiveness, while tarp color was studied for weed control.

### Santa Maria

These trials are located in the northern most southern coastal California production area. The southern California production system and a variety adapted to southern California are utilized. These trials represent a very large investment and commitment by the farmer. At this site, the goal was to compare the efficacy of bed-applied MeBr alternatives applied by drip irrigation and shank application vs. the standard shank application containing MeBr. In addition, VIF was investigated as a means to further reduce potential emissions and risk of soil fumigants and enhance fumigant effectiveness, while tarp color was studied for weed control. A broccoli residue/solarization/broccoli residue + solarization trial was scheduled to go in at this site, but due to events beyond control this trial could not be established.

**Oxnard, Site #1**

This is a southern coastal California location using the southern California production system and a variety adapted to southern California. The goal was to compare the efficacy of alternative MeBr preplant soil fumigants shank applied on the flat vs. the standard shank application containing MeBr. Fumigants tested included Telone, chloropicrin, and metab-sodium.

**Oxnard, Site #2**

This is a southern coastal California location using the southern California production system and a variety adapted to southern California. This replicated trial represents a very large investment and commitment by the farmer. Here, the goal was to compare the efficacy of bed-applied alternative methyl bromide preplant soil fumigants applied by drip irrigation and shank application vs. the standard shank application containing MeBr. VIFs and rates of MeBr alternatives were investigated as a means to further reduce potential emissions and risk of soil fumigants and enhance fumigant effectiveness. This trial contained replicated treatments.

**Irvine, Orange County**

This is a southern coastal California location using the southern California production system and a variety adapted to southern California. The goal was to compare the efficacy of preplant, bed-applied methyl bromide alternative soil fumigants applied by drip irrigation and shank application vs. the standard shank application containing MeBr. In addition, VIF and rates of MeBr alternatives were investigated as a means to further reduce potential emissions and risk of soil fumigants and enhance fumigant effectiveness.

**Merced**

This is a San Joaquin Valley location, which has a production system and needs distinctly different from those of coastal California production areas. The goal at this site was to compare the efficacy of preplant methyl bromide alternative soil fumigants shank applied on the flat vs. the standard shank application containing MeBr.

**Results**

**Watsonville, Site #1**

Data and specific trial treatments are presented in Table 5. A map of this trial is located in Appendix E. Data was not taken from all treatments established due to logistical constraints. Total yields of the treatments from which data was collected ranged from 100.4% to 109.4% of the total yield from the farmers' standard practice. Total yield from drip applied fumigants appears to be on par with that of shank applied fumigants in this trial. In this trial the utility of VIF is unclear as it marginally *increased* the total yield under one MeBr alternative (Chloropicrin, 200 lbs/A), and marginally *decreased* total yield in another (Telone C35, 350 lbs/A). While total yields from all treatments from which data was collected exceeded that of the farmers' standard practice, it should be noted that this farm has a 15+ year history of preplant soil fumigation with MeBr.

**Watsonville, Site #2**

Data and specific trial treatments are presented in Table 6. A map of this trial is located in Appendix E. Total yields from treatments ranged from 101.7% to 120.4% of the total yield from the farmers' standard practice. Total yield from all drip applied fumigant treatments exceeded that of the farmers' standard practice in this trial. The drip applied fumigant treatments Cholorpicrin EC at 24 gal/A with standard green tarp and Telone C35 EC at 35 gal/A with standard green tarp, treatments nearly comparable to the farmers' standard practice of MeBr/Pic 67/33 at 325 lbs/A with standard green tarp, produced total yield increases of 10.6% and 1.7% over the farmers' standard practice respectively. In those drip applied fumigant treatments where a standard clear tarp was utilized, total yield increases over farmers' standard practice ranged from 13.4% to 13.7%. In those drip applied fumigant treatments where a VIF clear tarp was utilized, total yield increases over farmers' standard practice ranged from 20.4% to 35.0%.

Although total yield was up in those drip applied fumigant treatments containing a clear tarp, so were the weeding costs (see Table 7). Estimated per acre weeding costs for a drip applied fumigant with green tarp averaged $91.26. Estimated per acre weeding costs for a drip applied fumigant with a clear VIF tarp were $466.89. Estimated per acre weeding costs for a drip applied fumigant with a clear standard tarp were $615.85. This represents a 512% increase in weeding costs over standard green tarp for clear VIF tarp, and a 675% increase in weeding costs over standard green tarp for standard clear tarp. Although estimated weeding costs for drip applied fumigant treatments with a clear VIF tarp were about $149.00 lower than drip applied fumigant treatments with a clear standard tarp, VIF tarp is presently projected to be approximately $400.00 more per acre than standard tarp.

**Santa Maria**

Drip Fumigation Trial. Data and specific trial treatments are presented in Table 8. A map of this trial is located in Appendix E. Total yields from treatments ranged from 73.8% to 107.5% of the total yield from the farmers' standard practice. Total yield overdrip applied fumigant treatments averaged 95.9% of the farmers' standard practice in this trial. Treatments involving nonfumigated soil averaged 79.8% of the total yield of the farmers' standard practice. Total yield over drip treatments with black standard, clear standard and clear VIF tarp averaged 91.9%, 95.3% and 100.5% of the farmers' standard practice in this trial. Over rates, tarp color and type, average total yield of treatments containing Chloropicrin EC averaged 93.2% of the farmers' standard practice, while Telone C35 EC averaged 98.6%. The worst and best performing treatments containing Chloropicrin EC were Chloropicrin EC at 14 gal/A with standard clear tarp and Chloropicrin EC at 14 gal/A with VIF clear tarp, which had total yields of 80.2% and 104.2% of the farmers' standard practice. The worst and best performing treatments containing Telone C35 EC were Telone C35 EC at 35 gal/A with VIF clear tarp and Telone C35 EC at 35 gal/A with standard clear tarp, which had total yields of 93.2% and 103.4% of the farmers' standard practice.

Neither Chloropicrin EC nor Telone C35 EC have much herbicidal activity. Figures 13 and 14 show a bed treated with Chloropicrin EC, and Figures 15 and 16, a similar bed treated according to the farmers' standard practice. Comparison of the figures clearly indicates the absence of herbicidal activity in Chloropicrin. Weed control using drip applied fumigants remains a major issue and will require considerable work.

Bed Fumigation Trial Data and specific trial treatments are presented in Table 9. A map of this trial is located in Appendix E. Total yields of the treatments ranged from 88.8% to 98.6% of the total yield from the farmers' standard practice. Shank applied Chloropicrin at 200 lbs/A with standard clear tarp yielded 88.8% of the farmers' standard practice. Chloropicrin at 200 lbs/A with VIF clear tarp had a 7.2% *increase* over Chloropicrin at 200 lbs/A with standard clear tarp for 95.9% of the yield from the farmers' standard practice. Shank applied Telone C35 at 350 lbs/A with standard clear tarp yielded 98.6% of the farmers' standard practice. Telone C35 shank applied at 350 lbs/A with VIF clear tarp had a 1.5% *decrease* from that of Telone C35 at 350 lbs/A with standard clear tarp. Developing information on sufficient plant back time, the time from fumigation to planting, will be critical to avoiding phytotoxicity of some methyl bromide alternatives when combined with tarps that are relatively impermeable.

**Oxnard, Site #1**

Data and specific trial treatments are presented in Table 10. A map of this trial is located in Appendix E. In this particular trial all Telone and Chloropicrin materials were shank applied on the flat. The metam sodium in the Chloropicrin + metam sodium treatment was applied through the drip irrigation system. Total yields from treatments ranged from 92.4% to 98.4% of the total yield from the farmers' standard practice. Neither Chloropicrin nor Telone C35 have much herbicidal activity. It is interesting to note that the best performing alternative to methyl bromide was the Chloropicrin at 200 lbs/A + metam sodium at 40 gal/A under standard clear tarp, a treatment which combined a material for control of soil-borne fungal pathogens with a material that can control weeds near the soil surface if applied properly and well.

**Oxnard, Site #2**

Analysis of variance is presented in Table 11, data and specific treatments are presented in Table 12. A map of this trial is located in Appendix E. Significant tarp ($P = 0.038$) and fumigant ($P = 0.008$) effects on total yield were detected. A significant fumigant x tarp effect was not detected. However, all treatments which combined a fumigant plus VIF tarp were numerically lower than their respective fumigant plus standard tarp.

Total yields from treatments ranged from 85.3% to 107.2% of the total yield from the farmers' standard practice. Total yield over drip applied and shank applied fumigant treatments averaged 99.7% and 100.5% of the farmers' standard practice in this trial respectively. Treatments involving nonfumigated soil averaged 85.8% of the total yield of the farmers' standard practice. Total yield over drip treatments with clear standard and clear VIF tarp averaged 101.1% and 98.3% of the farmers' standard practice in this trial. Total yield over shank applied treatments with clear standard and clear VIF tarp averaged 104.4% and 98.8% of the farmers' standard practice in this trial respectively. Over rates and tarp type, average total yield of treatments containing Chloropicrin EC averaged 100.5% of the farmers' standard practice, while Telone C35 EC averaged 98.9%. The worst and best performing treatments containing Chloropicrin EC and their yield relative to the farmers' standard practice were Chloropicrin EC at 14 gal/A with standard clear tarp, 99.7%, = Chloropicrin EC at 20 gal/A with VIF clear tarp, 99.7%, and Chloropicrin EC at 14 gal/A with VIF clear tarp, 102.0%. The worst and best performing treatments containing Telone C35 EC were Telone C35 EC at 35 gal/A with VIF clear tarp and Telone C35 EC at 21 gal/A with standard clear tarp, which had total yields of 92.6% and 106.0% of the farmers' standard practice respectively. Total yield, relative to the farmers' standard practice, over tarp type with a methyl bromide alternative was 102.7% and 98.5% for standard clear tarp and VIF clear tarp respectively in this trial.

On average, those treatments involving VIF clear tarp realized a 4% decrease in total yield relative to the farmers' standard practice. Developing information on sufficient plant back time will be critical to avoiding phytotoxicity of some methyl bromide alternatives when combined with tarps that are relatively impermeable.

**Irvine, Orange County**

Data and specific trial treatments are presented in Table 13. A map of this trial is located in Appendix E. Total yields from treatments ranged from 93.5% to 104.7% of the total yield from the farmers' standard practice. In this trial total yield over drip applied and shank applied fumigant treatments averaged 98.3% and 100.2% of the farmers' standard practice respectively. The nonfumigated soil treatment resulted in 101.4% of the total yield of the farmers' standard practice. Yield from plots which received drip applied fumigants and were initially tarped with clear VIF tarp and then tarped over with black standard tarp at planting (due to weed concerns) had an average total yield reduction of 2.7% relative to the same fumigant treatments with standard black tarp. This suggests a potential plant back problem, and thus it will be critical to develop information on sufficient plant back time to avoid phytotoxicity of some methyl bromide alternatives when combined with tarps that are relatively impermeable.

**Merced**

In this particular trial all Telone and Chloropicrin materials were shank applied on the flat. Data and treatments are presented in Table 14. Total yields from treatments ranged from 56.7% to 104.8% of the total yield from the farmers' standard practice. The best performing methyl bromide alternative was Telone C35, with 87.8% of the total yield from the farmers' standard practice. As a methyl bromide alternative, Chloropicrin alone shank applied on the flat provided 71.9% of the total yield from the farmers' standard practice. The utility of Telone C35 or Chloropicrin alone is questionable as neither Chloropicrin or Telone C35 have much herbicidal activity, and weeds are the primary pest in strawberry production in the San Joaquin Valley.

**Table 3. 1998-1999 On Farm Methyl Bromide Alternatives Trials By Growing District**

| Growing season | District | Number of sites |
|---|---|---|
| 1998-1999 | Watsonville | 2 |
| | Santa Maria | 1 |
| | Oxnard | 2 |
| | Orange/San Diego | 1 |
| | San Joaquin Valley | 1 |
| | Total | 7 |

## Table 4. List of 1998-1999 On Farm Alternative Treatments by Coastal Location

Trials sponsored by CSC/USDA-ARS/CDPR PMA

| Location | Fumigant | Application method | Standard tarp | Color | VIF Tarp | Color |
|---|---|---|---|---|---|---|
| Watsonville | MeBr/Chloropicrin | Bed fumigation, shank | x | Clear | x | Clear |
| Site #1 | Telone C35 | Bed fumigation, shank | x | Clear | x | Clear |
| | Telone C35EC | Bed fumigation, drip | x | Clear | x | Clear |
| | Chloropicrin | Bed fumigation, shank | x | Clear | x | Clear |
| | Chloropicrin EC | Bed fumigation, drip | x | Clear | x | Clear |
| Watsonville | MeBr/Chloropicrin | Bed fumigation, shank | x | Green | x | Clear |
| Site #2 | Telone C35 | Bed fumigation, shank | x | Green | x | Clear |
| | Telone C35EC | Bed fumigation, drip | x | Clear, green | x | Clear |
| | Chloropicrin | Bed fumigation, shank | x | Green | x | Clear |
| | Chloropicrin EC | Bed fumigation, drip | x | Clear, green | x | Clear |
| Santa Maria | Untreated | -- | x | Clear, black | x | Clear |
| | MeBr/Chloropicrin | Bed fumigation, shank | x | Clear, black | x | Clear |
| | Telone C35 | Bed fumigation, shank | x | Clear, black | x | Clear |
| | Telone C35EC | Bed fumigation, drip | x | Clear, black | x | Clear |
| | Chloropicrin | Bed fumigation, shank | x | Clear, black | x | Clear |
| | Chloropicrin EC | Bed fumigation, drip | x | Clear, black | x | Clear |
| Oxnard | MeBr/Chloropicrin | Flat fumigation, shank | x | Clear | | |
| Site #1 | Telone C35 | Flat fumigation, shank | x | Clear | | |
| | Chloropicrin | Flat fumigation, shank | x | Clear | | |
| | Chloropicrin + Vapam | Flat fumigation, shank + drip, bed | x | Clear | | |
| Oxnard | Untreated | -- | x | Clear | x | Clear |
| Site #2 | MeBr/Chloropicrin | Bed fumigation, shank | x | Clear | x | Clear |
| | Telone C35 | Bed fumigation, shank + drip | x | Clear | x | Clear |
| | Telone C35EC | Bed fumigation, shank + drip | x | Clear | x | Clear |
| | Chloropicrin | Bed fumigation, shank | x | Clear | x | Clear |
| | Chloropicrin EC | Bed fumigation, drip | x | Clear | x | Clear |
| Orange County | MeBr/Chloropicrin | Bed fumigation, shank | x | Black | | |
| | Telone C35 | Bed fumigation, shank | x | Black | | |
| | Telone C35EC | Bed fumigation, drip | x | Black | x | Clear at fumigation., replaced with standard black tarp |
| | Chloropicrin | Bed fumigation, shank | x | Black | | |
| | Chloropicrin EC | Bed fumigation, drip applied | x | Black | x | Clear at fumigation., replaced with standard black tarp |

Table 5. Results of Alternative Treatments - Watsonville, Site #1.

| | Treatment | Total yield as a percent of farmer standard practice | Percent increase over farmer standard practice |
|---|---|---|---|
| 1 | MeBr/Pic 67/33, 325 lbs/A, std clear tarp[1] | 100.0% | -- |
| 2 | Chloropicrin EC, 24 gal/A, std clear tarp | 107.3% | 7.3% |
| 3 | Telone C35 EC, 35 gal/A, std clear tarp | 100.4% | 0.4% |
| 4 | Chloropicrin, 200 lbs/A, std clear tarp | 102.1% | 2.1% |
| 5 | Chloropicrin, 200 lbs/A, VIF clear tarp | 103.9% | 3.9% |
| 6 | Telone C35, 240 lbs/A, std clear tarp | 105.0% | 5.0% |
| 7 | Telone C35 350 lbs/A, std clear tarp | 109.4% | 9.4% |
| 8 | Telone C35, 350 lbs/A, VIF clear tarp | 106.7% | 6.7% |
| 9 | MeBr/Pic 67/33, 325 lbs/A, VIF clear tarp | 106.1% | 6.1% |

1 Farmers' standard practice.

**Table 6. Results of Alternative Treatments - Watsonville, Site #2.**

| Treatment | Total yield as a percent of farmer standard practice | Percent increase over farmer standard practice |
|---|---|---|
| MeBr/Pic 67/33, 325 lbs/A, std green tarp[1] | 100.0% | -- |
| Chlororpicrin EC, 24 gal/A, std green tarp | 110.6% | 10.6% |
| Chlororpicrin EC, 24 gal/A, std clear tarp | 113.7% | 13.7% |
| Chlororpicrin EC, 24 gal/A, VIF clear tarp | 135.0% | 35.0% |
| Telone C35 EC, 35 gal/A, std green tarp | 101.7% | 1.7% |
| Telone C35 EC, 35 gal/A, std clear tarp | 113.4% | 13.4% |
| Telone C35 EC, 35 gal/A, VIF clear tarp | 120.4% | 20.4% |

1 Farmers' standard practice.

**Table 7. Weeding Costs Using Different Tarp (Mulch) Types - Watsonville, Site #2.**

Costs estimated for weeding by hand.

| **Treatment** | **Estimated costs to handweed from 12/11/99-3/7/99 ($/acre)** | **Estimated hand weeding costs from 12/11/99-3/7/99 over tarp type and/or color ($/acre)** |
|---|---|---|
| Telone C35 EC, 35 gal/A, std clear tarp | $664.13 | $615.85 |
| Cholorpicrin EC, 24 gal/A, std clear tarp | $567.57 | |
| Telone C35 EC, 35 gal/A, VIF clear tarp | $515.76 | $466.89 |
| Cholorpicrin EC, 24 gal/A, VIF clear tarp | $418.03 | |
| Cholorpicrin EC, 24 gal/A, std green tarp | $109.51 | $91.26 |
| Telone C35 EC, 35 gal/A, std green tarp | $73.01 | |

**Table 8. Drip Fumigation Trial Results - Santa Maria**

| Treatment | Total yield as a percent of farmer standard practice | Percent increase or decrease over farmer standard practice |
|---|---|---|
| MeBr/Pic, 75/25, 300 lbs/A, std clear tarp[1] | 100.0% | -- |
| MeBr/Pic, 75/25, 300 lbs/A, std black tarp | 86.6% | -13.4% |
| MeBr/Pic, 75/25, 300 lbs/A, VIF clear tarp | 107.5% | 7.5% |
| Nonfumigated, std clear tarp | 73.8% | -26.2% |
| Nonfumigated, std black tarp | 85.7% | -14.3% |
| Chloropicrin EC, 14 gal/A, std clear tarp | 80.2% | -19.8% |
| Chloropicrin EC, 14 gal/A, std black tarp | 86.8% | -13.2% |
| Chloropicrin EC, 14 gal/A, VIF clear tarp | 104.2% | 4.2% |
| Chloropicrin EC, 24 gal/A, std clear tarp | 94.9% | -5.1% |
| Chloropicrin EC, 24 gal/A, std black tarp | 88.8% | -11.2% |
| Chloropicrin EC, 24 gal/A, VIF clear tarp | 104.0% | 4.0% |
| Telone C35 EC, 21 gal/A, std clear tarp | 102.5% | 2.5% |
| Telone C35 EC, 21 gal/A, std black tarp | 98.3% | -1.7% |
| Telone C35 EC, 21 gal/A, VIF clear tarp | 100.6% | 0.6% |
| Telone C35 EC, 35 gal/A, std clear tarp | 103.4% | 3.4% |
| Telone C35 EC, 35 gal/A, std black tarp | 93.8% | -6.2% |
| Telone C35 EC, 35 gal/A, VIF clear tarp | 93.2% | -6.8% |

1 Farmers' standard practice.

**Table 9. Bed Fumigation Trial Results - Santa Maria**

| | Treatment | Total yield as a percent of farmer standard practice | Percent decrease below farmer standard practice |
|---|---|---|---|
| 1 | MeBr/Pic 75/25, 300 lbs/A, std clear tarp[1] | 100.0% | -- |
| 2 | Chloropicrin, 200 lbs/A, std clear tarp | 88.8% | -11.2% |
| 3 | Chloropicrin, 200 lbs/A, VIF clear tarp | 95.9% | -4.1% |
| 4 | Telone C35, 350 lbs/A, std clear tarp | 98.6% | -1.4% |
| 5 | Telone C35, 350 lbs/A, VIF clear tarp | 97.2% | -2.8% |

1 Farmers' standard practice.

**Table 10. Results of Alternative Treatments - Oxard, Site #1**

| Treatment | Total yield as a percent of farmer standard practice | Percent decrease below farmer standard practice |
|---|---|---|
| 1 MeBr/Pic 57/43, 325 lbs/A, std clear tarp[1] | 100.0% | -- |
| 2 Telone C35 EC, 388 lbs/A, std clear tarp | 93.9% | -6.1% |
| 3 Telone C35, 435 lbs/A, std clear tarp | 92.5% | -7.5% |
| 4 Chloropicrin, 200 lbs/A, std clear tarp | 92.4% | -7.6% |
| 5 Chloropicrin, 200 lbs/A + metam sodium, 40 gal/A, std clear tarp | 98.4% | -1.6% |

1 Farmers' standard practice

**Table 11. Analysis of Variance for Total yield, Oxnard Site #2**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Tarp | 1 | 71,451,683 | 71,451,683 | 4.56 | 0.038 |
| Fumigant | 9 | 412,973,934 | 45,885,993 | 2.93 | 0.008 |
| Block | 2 | 11,628,707 | 5,814,353 | 0.37 | 0.692 |
| Error | 47 | 737,006,588 | 15,680,991 | | |
| Total | 59 | 1,233,060,911 | | | |

Table 12. **Results of Alternative Treatments - Oxard, Site #2**

| | Treatment | Total yield as a percent of farmer standard practice | Percent increase or decrease over farmer standard practice | Within fumigant and fumigant rate percent yield decrease due to VIF |
|---|---|---|---|---|
| 1 | MeBr 75/25, 330 lbs/A, std clear tarp[1] | 100.0% | -- | |
| 2 | Nonfumigated, std clear tarp | 86.3% | -13.7% | |
| 3 | Chloropicrin, 120 lbs/A, std clear tarp | 103.7% | 3.7% | |
| 4 | Chloropicrin, 200 lbs/A, std clear tarp | 107.2% | 7.2% | |
| 5 | Telone C35, 240 lbs/A, std clear tarp | 101.4% | 1.4% | |
| 6 | Telone C35, 350 lbs/A, std clear tarp | 105.1% | 5.1% | |
| 7 | Chloropicrin EC, 14 gal/A, std clear tarp | 99.7% | -0.3% | |
| 8 | Chloropicrin EC, 20 gal/A, std clear tarp | 102.0% | 2.0% | |
| 9 | Telone C35 EC, 21 gal/A, std clear tarp | 106.0% | 6.0% | |
| 10 | Telone C35 EC, 35 gal/A, std clear tarp | 96.5% | -3.5% | |
| 11 | MeBr 75/25, 330 lbs/A, VIF clear tarp | 92.3% | -7.7% | -8% |
| 12 | Nonfumigated, VIF clear tarp | 85.3% | -14.7% | -1% |
| 13 | Chloropicrin, 120 lbs/A, VIF clear tarp | 100.1% | 0.1% | -4% |
| 14 | Chloropicrin, 200 lbs/A, VIF clear tarp | 100.6% | 0.6% | -7% |
| 15 | Telone C35, 240 lbs/A, VIF clear tarp | 98.9% | -1.1% | -2% |
| 16 | Telone C35, 350 lbs/A, VIF clear tarp | 95.4% | -4.6% | -10% |
| 17 | Chloropicrin EC, 14 gal/A, VIF clear tarp | 100.5% | 0.5% | 1% |
| 18 | Chloropicrin EC, 20 gal/A, VIF clear tarp | 99.7% | -0.3% | -2% |
| 19 | Telone C35 EC, 21 gal/A, VIF clear tarp | 100.4% | 0.4% | -6% |
| 20 | Telone C35 EC, 35 gal/A, VIF clear tarp | 92.6% | -7.4% | -4% |

1 Farmers' standard practice

**Table 13. Results of Alternative Treatments - Orange County**

| Treatment | Total yield as a percent of farmer standard practice | Percent increase or decrease over farmer standard practice |
|---|---|---|
| MeBr/Pic75/25, 235 lbs/A, std blk tarp[1] | 100.0% | -- |
| Nonfumigated, std blk tarp | 101.4% | 1.4% |
| Chloropicrin, 200 lbs/A, std blk tarp | 98.7% | -1.3% |
| Telone C35, 240 lbs/A, std blk tarp | 104.7% | 4.7% |
| Telone C35, 350 lbs/A, std blk tarp | 99.5% | -0.5% |
| Chloropicrin EC, 14 gal/A, std blk tarp | 103.2% | 3.2% |
| Chloropicrin EC, 14 gal/A, clear VIF tarp replaced with std blk tarp | 102.7% | 2.7% |
| Chloropicrin EC, 24 gal/A, std blk tarp | 99.8% | -0.2% |
| Chloropicrin EC, 24 gal/A, clear VIF tarp replaced with std blk tarp | 102.5% | 2.5% |
| Telone C35EC, 21 gal/A, std blk tarp | 99.6% | -0.4% |
| Telone C35EC, 21 gal/A, clear VIF tarp replaced with std blk tarp | 93.5% | -6.5% |
| Telone C35EC, 35 gal/A, std blk tarp | 95.6% | -4.4% |
| Telone C35EC, 35 gal/A, clear VIF tarp replaced with std blk tarp | 94.0% | -6.0% |

Farmers' standard practice

**Table 14. Results of Alternative Treatments - San Joachim Valley**

| Treatment | Total yield as a percent of farmer standard practice | Percent increase or decrease over farmer standard practice |
|---|---|---|
| 1 MeBr[1] | 100.0% | -- |
| 2 MeBr/Pic | 104.8% | 4.8% |
| 3 Nonfumigated, std blk tarp | 56.7% | -43.3% |
| 4 Chloropicrin, std blk tarp | 71.9% | -28.1% |
| 5 Telone C35, std blk tarp | 87.8% | -12.2% |

1 Farmers' standard practice

**Figure 13. Weed pressure on the bed side in a drip applied fumigant treatment**

Photographed two weeks after planting.

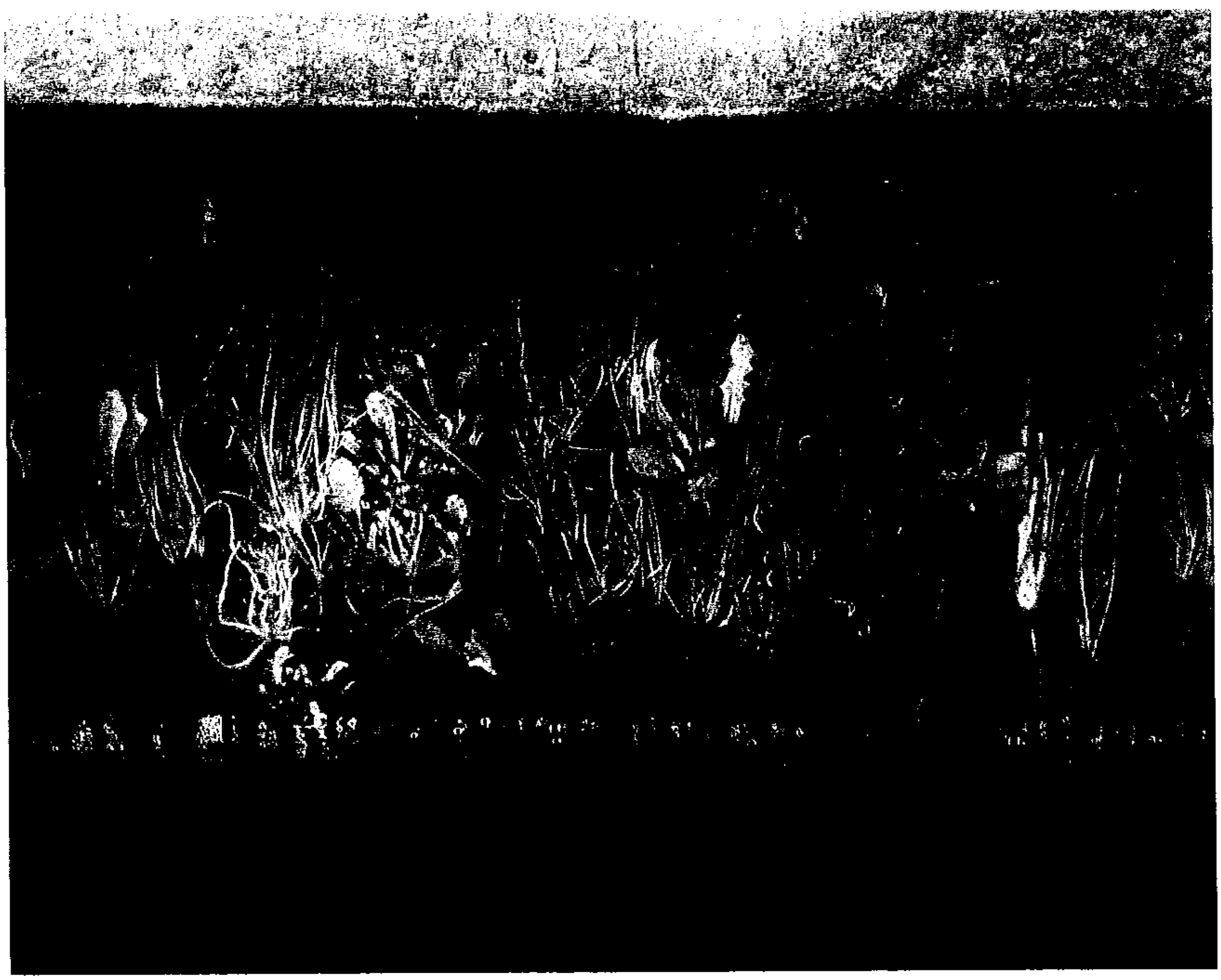
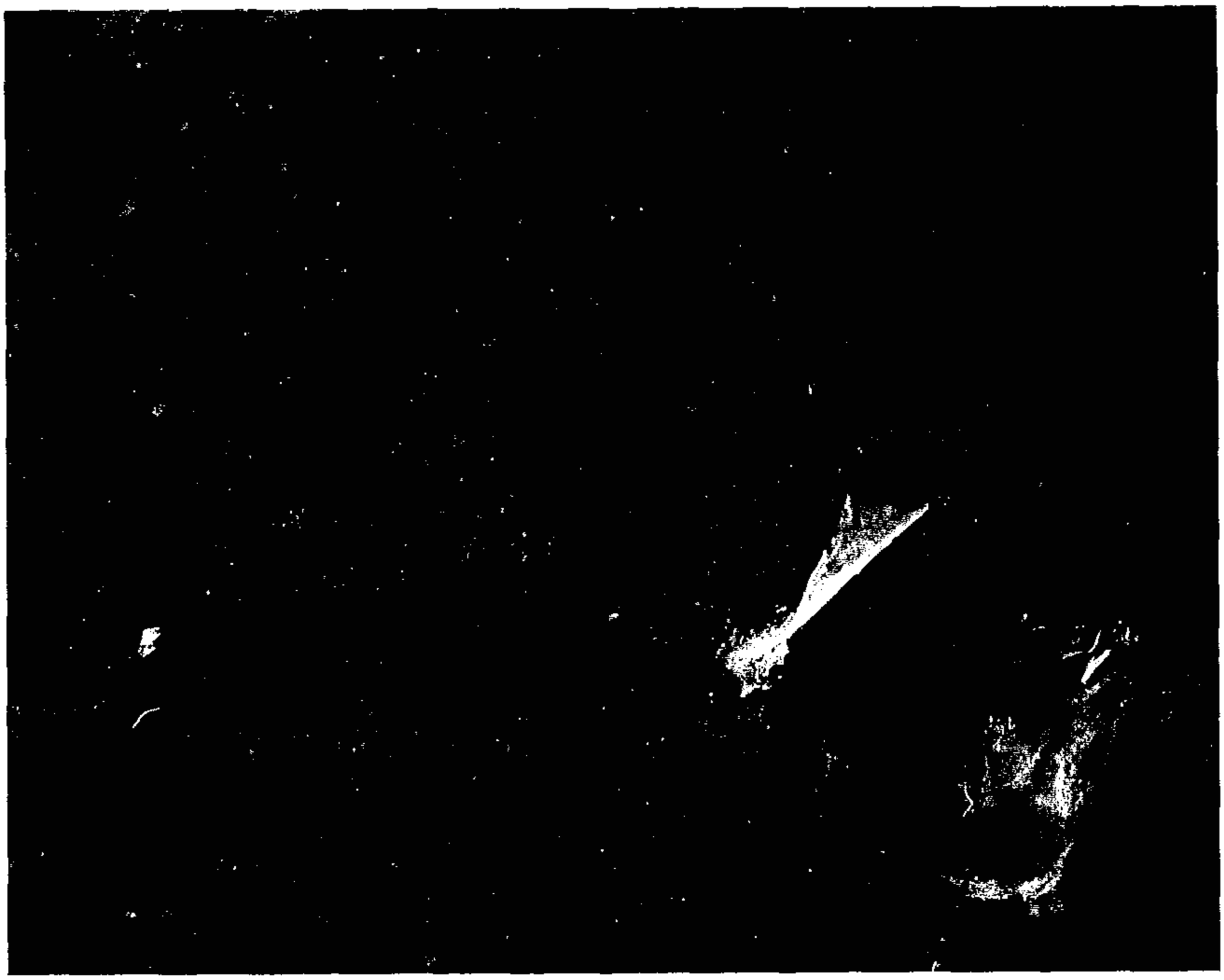


**Figure 14. Weed pressure on the bed top in a drip applied fumigant treatment.**

Photographed two weeks after planting.

**Figure 15. Weed pressure on the bed side in the farmers' standard preplant fumigation.** Photographed two weeks after planting.

**Figure 16. Weed pressure on the bed top in standard preplant fumigation treatment.**
Photographed two weeks after planting.



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# Appendix B

## Technical Meetings and Field Days

1. **Copies of *The Pink Sheet*, announcing dates and venues**
2. **Technical handouts distributed**
3. **Photographs made at Watsonville, 4 May 1999**

## Dates

**3 February 1999, Watsonville**
**25 February 1999, Fresno**
**10 March 1999, Irvine**
**15 April 1999, Santa Maria**
**4 May 1999, Watsonville**

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# the PINK SHEET

STRAWBERRY NEWS BULLETIN

99-9 April 19, 1999

## Watsonville Strawberry Research Field Day Announcement

The annual Monterey Bay Academy field day and the University of California, Davis, Pomology group field day will be held on Tuesday, May 4. These are excellent opportunities for farmers to see and discuss work being conducted by UC and USDA researchers.

**Monterey Bay Academy Field Day**
The Monterey Bay Academy strawberry field day will run from 9:00 a.m. – 12:00 p.m. The Monterey Bay Academy is located approximately 3 miles north of Beach Road on San Andreas Road, in Watsonville.

Researchers scheduled to speak include:

| | | |
|---|---|---|
| 9:00-9:30 | John Duniway | Response of Strawberry to Soil Fumigation, Alternatives to Methyl Bromide, Use of Virtually Impermeable Films, Crop Rotation and Organic Soil Amendments |
| 9:30-10:00 | Husein Ajwa | Evaluation of Drip Irrigation Systems to Deliver Alternative Fumigants to Methyl Bromide for Strawberry Production |
| 10:00-10:30 | Greg Browne | Cultural and Genetic Strategies for Management of *Phytophthora* on California Strawberries |
| 10:30-11:00 | Ed Civerolo | Bacterial Angular Leafspot (*Xanthomonas fragariae*) Disease of Strawberry Research |
| 11:00-11:30 | Doug Gubler | Botrytis and Powdery Mildew of Strawberry and their Control |
| 11:30-12:00 | Frank Martin | Management of Root Diseases and Rhizosphere Ecology of Strawberry |

**UC Davis Pomology Group Field Day**
The University of California, Davis, Pomology group field day will be held from 1:30 p.m. – 4:00 p.m at the Watsonville Research Facility. The facility is located on Dairy Road, ½ mile west of Beach Road on San Andreas Road in Watsonville. Doug Shaw, Kirk Larson, Tom Gordon and Frank Zalom will present information on strawberry breeding and cultural practices, fumigation alternatives and tarp treatment, recent research on Verticillium wilt in high elevation strawberry nurseries, and mite resistance and control/thrip control.

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STRAWBERRY NEWS BULLETIN

99-1 January 7, 1999

## 1999 Strawberry Research Conference, Watsonville, CA
## Program Schedule

| | |
|---|---|
| Place: | UCCE Santa Cruz County, 1432 Freedom Blvd., Watsonville, CA |
| Date and Time: | 8:30 am - 4:00 pm, February 3, 1999 |

There is no cost to attend the conference, but lunch and refreshments will be provided to participants who register in advance and pay a $15.00 fee.

| | |
|---|---|
| 8:30 am | **Registration** |
| 9:00 | Regulatory Update<br>*Mr. Dave Moeller, Santa Cruz Co. Ag. Commissioner* |
| 9:30 | California Strawberry Commission Research Activities Update<br>*Dr. Frank Westerlund, California Strawberry Commission* |
| 9:55 | Strawberry Breeding and Cultural Practice Research Update<br>*Dr. Douglas Shaw, UC Davis Pomology Dept.* |
| 10:25 | **Break** |
| 10:35 | Mite and Lygus Control Update<br>*Dr. Frank Zalom, Director, UC IPM Program* |
| 11:05 | Research Update on Foliar Disease Control<br>*Dr. Doug Gubler, UC Davis Dept. of Plant Pathology* |
| 11:35 | Alternatives to Methyl Bromide<br>*Dr. John Duniway, UC Davis Dept. of Plant Pathology* |
| 12:00 Noon | **Lunch** |
| 12:50 | Research Update on Strawberry Cultural Practices<br>*Kirk D. Larson, UC Davis Dept. of Pomology* |
| 1:15 | Biology and Management of Verticillium Wilt in Strawberry Nurseries<br>*Dr. Tom Gordon, UC Davis Dept. of Plant Pathology* |
| 1:40 | Strawberry Yields of Normal vs. "J-Rooted" Plants<br>*Mr. Warren Bendixen, UCCE, Sta. Barbara Co.* |
| 2:05 | Angular Leafspot Research Update<br>*Dr. Ed Civerolo, USDA/UC Davis Dept. of Plant Pathology* |
| 2:30 | **Break** |
| 2:45 | Phytophthora Biology and Management Research Update<br>*Dr. Greg Browne, USDA/UC Davis Dept. of Plant Pathology* |
| 3:10 | Biological Alternatives to Soil Fumigation,<br>*Dr. Frank Martin, USDA Salinas* |
| 3:35 | Applying Fumigants by Drip Irrigation<br>*Dr. Tom Trout, USDA Fresno* |
| 4:00 pm | **End** |

Six CE units have been requested for this conference.

For information and advance registration contact the Santa Cruz Coop. Extension Office at 1432 Freedom Blvd., Watsonville, CA 95076, phone 831-763-8006. Please note: only advance registration will guarantee a lunch ticket.

STRAWBERRY RESEARCH CONFERENCE, FEBRUARY 3, 1999, REGISTRATION FORM:
Please print

NAME: ______________________________ COMPANY: ______________________________

PHONE: ______________________________

NUMBER OF PEOPLE ATTENDING: ______ PAYMENT ENCLOSED: ______________________

**Conferencia Annual de Investigación en Fresas 1999, Watsonville, CA**
**Horario de Programa**

| | |
|---|---|
| Lugar: | UCCE Santa Cruz County, 1432 Freedom Blvd., Watsonville, CA |
| Fecha y Horario: | 3 Febrero, 1999, 8:30 am – 4:00 pm |

No hay costo para atender la conferencia, habra almuerzo y refrescos para los participantes que se registren en adelantado y pagen $15.00 para cubrir su almuerzo.

| | |
|---|---|
| 8:30 A.M. | **Registración** |
| 9:00 A.M. | Actualización Regulatorio<br>*Sr. Dave Moeller, Agente Comisionado de Agricultura, Condado de Santa Cruz* |
| 9:30 A.M. | Actividades Actualizadas Programa de Investigaciones de La Comisión de Fresa de California<br>*Dr. Frank Westerlund, Comisión de Fresa de California* |
| 9:55 A.M. | Mejoramiento Genético de Fresas y Actualizada Investigación de Práctica Cultural<br>*Dr. Douglas Shaw, Universidad de California Davis. Departamento de Pomología* |
| 10:25 A.M. | **Descanso** |
| 10:35 A.M. | Actualizado Control de Ácaro y Lygus<br>*Dr. Frank Zalom, Director, Programa IPM de la Universidad de California* |
| 11:05 A.M. | Actualizada Investigación en Control de Enfermedades de Follaje<br>*Dr. Doug Gubler, Universidad de California Davis, Departamento de Patología Vegetal* |
| 11:35 A.M. | Alternativos al Bromuro de Metilo<br>*Dr. John Duniway, Universidad de California Davis, Departamento de Patología Vegetal* |
| 12:00 | **Almuerzo** |
| 12:50 P.M. | Actualizada Investigación Prácticas Cultural de Fresas<br>*Dr. Kirk Larson, Universidad de California Davis, Departamento de Pomología* |
| 1:15 P.M. | Biología y Control de Verticillium Marchito en Vivero de Fresas<br>*Dr. Tom Gordon, Universidad de California Davis, Departamento de Patología Vegetal* |
| 1:40 P.M. | Rendimientos de Fresa Normal vs. Planta "J-Raices"<br>*Sr. Warren Bendixen, Universidad de California Cooperativa Extención, Condado de Santa Barbara* |
| 2:05 P.M. | Investigación Actualizada de la Mancha Angular de la Hoja<br>*Dr. Ed Civerolo, USDA/ Universidad de California Davis, Departamento de Patología Vegetal* |
| 2:30 P.M. | **Descanso** |
| 2:45 P.M. | Pytophthora Biología y Actualizada Investigación en Control<br>*Dr.Greg Browne, USDA/ Universidad de California Davis, Departamento de Patología Vegetal* |
| 3:10 P.M. | Alternativos Biológicos al Bromuro de Metilo<br>*Dr. Frank Martin, USDA Salinas* |
| 3:35 P.M. | Aplicando Fumigantes por Gotero de Irrigación<br>*Dr. Tom Trout, USDA Fresno* |
| 4:00 P.M. | **Final** |

Seis unidades para los "CE" han sido solicitados para esta conferencia.
Para mas información y registración en adelanto contacte la oficina de Extensión Coop. Santa Cruz
En 1432 Freedom, Blvd., Watsonville, CA 95076, telefono 831-763-8006.
**Por favor note:** Registración en adelanto le garantiza un tiquete para el almuerzo.

---

CONFERENCIA DE INVESTIGACION DE FRESAS, ENERO 12, 1999, FORMULARIO DE REGISTRO
Por favor llene:

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TELÉFONO: ______________ NÚMERO DE PERSONAS QUE VIENEN: ________ PAGO INCLUIDO: $________

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# the PINK SHEET

STRAWBERRY NEWS BULLETIN March 12, 1999

## Strawberry Field Day in Santa Maria

*University of California Coop. Extension, Santa Barbara County*

**Date: April 15, 1999**
**Time: 9:00AM-3:30 PM**

**Location: Gold Coast Farm - Ron Burk**
**Stowell Road – 0.4 mile east of Highway 101**

9:00AM
- Strawberry production on the Gold Coast Farm - Ron Burk, Grower
- New Tensiometers - Richard Morgan, Irrometers Company, Riverside, California
- Two Spotted Spider Mites and Lygus Control - Frank Zalom, UC Davis
- "J" root strawberry trial, Calcium foliar trial - Warren Bendixen, University of California, Santa Maria
- Botrytis on Strawberries - Albert Paulus, UC Riverside
- Strawberry flower diseases - Steve Koike, UC Monterey County

**Location: D & B Specialty Berry Farms - Daren Gee**
**0.5 mile east of Broadway on McCoy Lane**

11:30AM
- BBQ lunch sponsored by the California Strawberry Commission

12:30PM
- Strawberry varieties - Kirk Larson, University of California South Coast Research and Extension Center, and Doug Shaw, UC Davis
- Status of methyl bromide fumigation - Frank Westerlund, Christopher Winterbottom, California Strawberry Commission
- Production Practices - Daren Gee, Grower

# 1999 Strawberry Research Conference in Santa Maria
# Thursday, April 15, 1999

## *Registration Information*

**Instructions: Complete the conference registration form and <u>return to the CSC office by April 1, 1999</u>. Please use only one form for each registrant. This form can be copied if necessary. Please include your payment for lunch fees if applicable.* Mail to:**
**<u>California Strawberry Commission, P.O. Box 269, Watsonville, CA 95077-0269</u>**

Name:________________________Company Name:________________________________________

Street/BoxNo:________________________________________________________________________

City:______________________State:__________________Zip Code:________________________

Phone:_____________________Fax:___________________________________________________

| | | | |
|---|---|---|---|
| Industry Affiliation: (circle one) | Grower | UC Researcher/Extension | PCA |
| Shipper/Processor | Allied Industry | Other | |

***Registration will be complimentary for California strawberry growers, shippers, processors, researchers and farm advisors. All other industry-affiliated guests will be charged a nominal fee of $10.00 for lunch. (No Refunds will be given).***

## *Lunch*

_____ I will be attending the lunch. I will need an additional _____ lunch ticket(s).
(If additional tickets are requested, please see above if fees apply.)

**California Strawberry Commission**
**P.O. Box 269**
**Watsonville, CA 95077-0269**
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## STRAWBERRY NEWS BULLETIN

February 3, 1999

San Joaquin Valley

## *Strawberry Growers Meeting*

February 25, 1999 (8:00 am - 12:30 pm)

UC Cooperative Extension Office, 1720 S. Maple Ave, Fresno

**AGENDA**

| | |
|---|---|
| **8:00 - 8:05a.m.** | **Welcome** *Richard Molinar/Manuel Jimenez* |
| **8:05 - 8:50** | **Integrated Strawberry Production Management for the Central Valley**<br>*Dr. Kirk Larson -- UCCE Strawberry Specialist* |
| **8:50 - 9:10** | **Strawberry Varieties for the Central Valley**<br>*Maxwell Norton-Farm Advisor (Merced), Richard Molinar-Farm Advisor (Fresno)* |
| **9:10 - 9:30** | **Methyl Bromide Alternative Research** *same as above* |
| **9:30 - 9:55** | **Plastic Mulches** *Richard Molinar*<br>**2-year plantings** *Maxwell Norton* |
| **9:55 - 10:15** | **Break** |
| **10:15 - 11:00** | **Are You In Compliance? Grower Guidelines & Field Sanitation**<br>*Frances Pabrua, California Strawberry Commission* |
| **11:00 - 11:15** | **What's New for 1999 - open forum** |
| **11:15 - 12:30** | **Insect and Spider Mite Workshop** *Carolyn Watson (Larry Whitted Consulting)* |

**<u>3 hours continuing education</u> applied - for PCA's and Growers no charge.**

**Co-sponsors -** UC Cooperative Extension Fresno/Tulare
California Strawberry Commission
Biologically Integrated Strawberry Systems Project (BISS)
Wawona Frozen Foods

## FOR MORE INFORMATION -

**Richard Molinar (559) 456-7555 or Manuel Jimenez (559) 733-6791**

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February 12, 1999

*California Strawberry Industry*

# Research Conference - March 10, 1999

## Conference Registration and Information

*Program Highlights*

- Tour of South Coast Experiment Station test plots with Dr. Kirk Larson
- Brief presentations of Strawberry Commission funded research in the areas of: breeding and cultural research, disease management, and soil complex including methyl bromide update and insect and mite management.
- Afternoon exhibits and question and answer session with project leaders.

| | |
|---|---|
| 8:00 a.m. | Registration/Coffee and Introductions |
| 8:30 a.m. | Pomology Research Presentation including discussion and sampling of new selections<br>Drs. Kirk Larson and Doug Shaw |
| 9:00 a.m | Tour of South Coast Strawberry Field Research Facilities: Dr. Kirk Larson |
| 12:00 p.m. | Barbecue Lunch |
| 12:45 p.m. | Strawberry Commission Report on Research and Regulatory Issues |
| 1:00 p.m. | Research Update on Foliar Disease Control: Dr. Doug Gubler |
| 1:30 p.m. | Mite, Lygus and Whitefly Update: Dr. Frank Zalom |
| 2:00 p.m. | Poster Session and Exhibits – One-on-One Question and Answer Session with UC and USDA Scientists Funded by the Strawberry Industry |
| 3:00 p.m. | Conclude |

Four and a half (4 ½) CE have been requested for this conference.

# Conferencia Annual de Investigación en Fresas
## 10 de Marzo de 1999
## Horario de Programa

| | |
|---|---|
| 8:00 a.m. | Registro, Café y Introdución, Dave Riggs |
| 8:30 a.m. | Presentación de Investigación en Pomologia, Drs. Larson y Shaw |
| 9:00 a.m. | Excursion por las Parcelas de Prueba del Centro Experimental de la Costa Sur |
| 12:00 p.m. | Almuerzo (barbacoa) |
| 12:45 p.m. | Reporte en Investigaciónes y Temas Regulatorios de la Comisión de Fresa de California |
| 1:00 p.m. | Actualizada Investigación en Control de Enfermedades de Follage, Dr. Gubler |
| 1:30 p.m. | Actualización de Ácaro, Lygus y Mosca Blanca, Dr. Zalom |
| 2:00 p.m. | Preguntas y Respuestas: Sesión de Exhibiciónes y Posters con los Cientificos de la Universidad de California y USDA Financiados por la Industria de Fresas. |
| 3:00 p.m. | Final |

Cuatro punto cinco unidades para los "CE" han sido solicitados para esta conferencia.

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## 1999 Strawberry Research Conference at SCREC, Irvine, CA
## Wednesday, March 10, 1999

### *Registration Information*

**Instructions: Complete the conference registration form and return to the CSC office by Feb. 28, 1999. Please use only one form for each registrant. This form can be copied if necessary. Please include your payment for lunch fees if applicable.* Mail to:**
California Strawberry Commission, P.O. Box 269, Watsonville, CA 95077-0269

Name:________________________Company Name:________________________________________

Street/BoxNo:______________________________________________________________________

City:______________________State:__________________Zip Code:________________________

Phone:______________________Fax:_________________________________________________

| | | | |
|---|---|---|---|
| Industry Affiliation: (circle one) | Grower | UC Researcher/Extension | PCA |
| | Shipper/Processor | Allied Industry | Other |

***Registration will be complimentary for California strawberry growers, shippers, processors, researchers and farm advisors. All other industry affiliated guests will be charged a nominal fee of $17.00 for lunch. (No Refunds will be given).***

### *Lunch*

_____ I will be attending the lunch. I will need an additional _____ lunch ticket(s).
(If additional tickets are requested, please see above if fees apply.)

### *Hotel Information*

The Westin South Coast Plaza, 686 Anton Boulevard, Costa Mesa, California 92626, (714)540-2500 will be the host hotel for this conference. The group rate for this conference is $130.00 per night, single or double occupancy. (local taxes apply) If you have not already done so, please contact the hotel directly for reservations.

All reservations must be received by February 16, 1999 in order to receive the group rate. Reservations received after February 16, 1999 will be subject to space and rate availability.

# Pomology Progress Report, South Coast Field Day 1999: Cultivar Improvement

Douglas V. Shaw and Kirk D. Larson, Department of Pomology, U.C. Davis

**U.C. Strawberry Breeding Program Overview.** The northern and southern California breeding programs have diverged in recent years due to the distinct varietal needs of the south coast and central coast production regions. As the two breeding programs have diverged, activities in both locations have increased. In 1998 over 10,000 seedlings were grown and evaluated at each location and over 500 new selections were entered into first stage of advanced testing. Program divergence has mandated two high- elevation nursery programs, with over 100 accession/harvest date combinations in 1998.

**Cultivars released in 1997.** There appears to be general acceptance of most of the recent UC releases. Extrapolation from estimated nursery acreage suggests that about 2,000 acres of Diamante, Aromas, and Gaviota will be in production in 1999, and that this acreage was limited by plant supply. The strengths and weaknesses of each cultivar on commercial scales appear about as expected from small plot research. Botrytis and color problems with Diamante were greater in 1998 than in the past, but only on the coast, and likely due in part to excessive wet conditions; good yields and excellent fruit quality were obtained inland. Due to its productivity and color, interest in Aromas is greater on the coast where Diamante problems were most obvious. A 4-year summary suggested that Camarosa outyields Gaviota in Watsonville, at least on a per-plant basis. Gaviota would need more plants per acre to be directly competitive; a decrease from 16" to 14" at 52" centers would suffice. Gaviota performed better in Santa Maria, out-yielding Camarosa substantially in 1998, due largely to its rain tolerance.

**Advanced selections.** Several of the 1994 selections from the Watsonville program have shown promise in two years of testing. The most advanced and the most exciting items are short day types intended as replacements for Camarosa from Santa Maria and north. Specific objectives are a plant that can be planted later and maintains a more compact plant form, has later initiation of production to avoid spring rain, suffers fewer disease problems, and has a lower cull rate to enhance harvest efficiency. Item 94.3-11 is very promising; it out-yielded Camarosa over two years with a smaller plant and lower cull rate. Item 94.3-10 has exceptional flavor, but may have too low yield to be directly competitive with Camarosa. Item 94.19-5 has exceptionally large fruit and a compact plant. No releases are expected in 1999, the earliest point at which a final decision on these items would be made is September 2000.

Promising selections from the South Coast program include a high-yielding item (94.256-607) with Verticillium wilt tolerance that is in a grower trial in Santa Maria, and more than one dozen 1996 selections that are in grower tests throughout the state. For southern California, breeding objectives include adaptation to early nursery digging, early fruit production, sustained yields throughout the winter and spring, a low cull rate, and environmental tolerance.

**Resistance Breeding.** Considerable effort has been invested in the development of superior germplasm with resistance/tolerance to Verticillium wilt and two-spotted mites. A collaborative project with Drs. Doug Gubler and Tom Gordon has established testing for Verticillium wilt resistance as a standard procedure in the evaluation of parental stock and advanced selections. Similarly, collaborative work with Dr. Frank Zalom has resulted in extensive information regarding germplasm tolerance/susceptibility to two-spotted mite injury. Most recently, collaborative work with Dr. Greg Browne was initiated with the intent to develop similar resistance evaluation efforts for Phytophthora root/crown rot.

# Evaluation of Drip Irrigation Systems to Deliver Alternative Fumigants to Methyl Bromide for Strawberry Production

Husein Ajwa and Tom Trout, USDA-ARS
Water Management Research Laboratory, Fresno, CA

**Objectives:** to determine the distribution and efficacy of Telone C35 EC, Vapam, and Chloropicrin applied through drip irrigation systems, and to develop optimum irrigation parameters for strawberry production under the alternative fumigants.

Variables that are being evaluated include fumigants application rate, amount of water used to apply the fumigants, and application of combinations of fumigants.

## FUMIGANT APPLICATION TREATMENTS

| Trt# | Treatment Description |
|---|---|
| 1 | Untreated control |
| 2 | MeBr/Chloropicrin bed shank injection @ 425 lb/ac (245 lb/ac-bed) |
| 3 | Telone/Chloropicrin (Telone C35) bed shank injection @ 425 lb/ac |
| 4 | Telone C35 EC drip applied @ 425 lb/ac in 15 mm net irrigation |
| 5 | Telone C35 EC drip applied @ 425 lb/ac in 25 mm net irrigation |
| 6 | Telone C35 EC drip applied @ 425 lb/ac in 35 mm net irrigation |
| 7 | Telone C35 EC drip applied @ 255 lb/ac in 25 mm net irrigation |
| 8 | Vapam (42%) drip applied @ 75 gal/ac in 25 mm net irrigation |
| 9 | Vapam (42%) drip applied @ 75 gal/ac in 35 mm net irrigation |
| 10 | Vapam (40%) drip applied @ 50 gal/ac in 25 mm net irrigation |
| 11 | Telone C35 EC @ 255 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 12 | Chloropicrin @ 160 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 13 | Chloropicrin ~ 160 lb/a~ drip applied in 25 mm net irrigation |

## IRRIGATION TREATMENTS

Strawberry yield in Telone C35 bed shank injection (at 425 lb/ac and 255 lb/ac) will be irrigated by three irrigation amounts [75% (Low), 100% (Med.), and 125% (High) of crop evapotranspiration].

MBA 1998-99

| # | Irrig | | | | MBA 98 plots (Fumigated Sept 6-8, 1998) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | (T13)-PicMw (25 mm) | (T9)-MvHw (35 mm) | (T5)-HtMw (25 mm) | (T12)-(Pic+Mv)Mw |
| 1 | M | Low Telone C35 Shank | High Telone C35 Shank | | (T7)-MtMw (25 mm) | (T8)-HvMw (25 mm) | (T10)-MvMw (25 mm) | (T2)-MeBr/Pic Shank |
| 2 | L | Low Telone C35 Shank | High Telone C35 Shank | | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) | (T13)-PicMw (25 mm) | (T6)-HtHw (35 mm) |
| 3 | H | Low Telone C35 Shank | High Telone C35 Shank | | (T4)-HtLw (15 mm) | (T12)-(Pic+Mv)Mw | (T8)-HvMw (25 mm) | (T9)-MvHw (35 mm) |
| 4 | H | High Telone C35 Shank | Low Telone C35 Shank | | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank | (T5)-HtMw (25 mm) |
| 5 | M | High Telone C35 Shank | Low Telone C35 Shank | | (T11)-(Mt+Mv)Mw | (T1)-Untreated control | (T12)-(Pic+Mv)Mw | (T4)-HtLw (15 mm) |
| 6 | L | High Telone C35 Shank | Low Telone C35 Shank | | (T9)-MvHw (35 mm) | (T3)-Telone/Pic Shank | (T1)-Untreated control | (T11)-(Mt+Mv)Mw |
| 7 | M | Low Telone C35 Shank | High Telone C35 Shank | | (T1)-Untreated control | (T4)-HtLw (15 mm) | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) |
| 8 | H | Low Telone C35 Shank | High Telone C35 Shank | | (T5)-HtMw (25 mm) | (T13)-PicMw (25 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank |
| 9 | L | Low Telone C35 Shank | High Telone C35 Shank | | (T12)-(Pic+Mv)Mw | (T2)-MeBr/Pic Shank | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) |
| 10 | M | High Telone C35 Shank | Low Telone C35 Shank | | (T10)-MvMw (25 mm) | (T11)-(Mt+Mv)Mw | (T9)-MvHw (35 mm) | (T8)-HvMw (25 mm) |
| 11 | L | High Telone C35 Shank | Low Telone C35 Shank | | (T3)-Telone/Pic Shank | (T6)-HtHw (35 mm) | (T11)-(Mt+Mv)Mw | (T1)-Untreated control |
| 12 | H | High Telone C35 Shank | Low Telone C35 Shank | | (T8)-HvMw (25 mm) | (T5)-HtMw (25 mm) | (T4)-HtLw (15 mm) | (T13)-PicMw (25 mm) |
| | | 35 ft | 35 ft | | 31 ft | 31 ft | 31 ft | 31 ft |

# Response of Strawberry to Soil Fumigation: Microbial Mechanisms and some Alternatives to Methyl Bromide

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The experiments reported here are part of a larger project supported by the California Strawberry Commission and ARS-USDA to research chemical and nonchemical alternatives to methyl bromide for preplant fumigation of soil in strawberry production. Chemical alternatives to methyl bromide have been tested in replicated field experiments at the Monterey Bay Academy near Watsonville, CA. Strawberry was grown every year, *Verticillium dahliae* was present in the soil, and bed fumigation treatments were applied in early October of each year. Two-row beds were shaped, fumigated (two shanks/bed, 15-20 cm deep, rates given per unit of treated bed area, which is 58% of the total area), and covered with black plastic mulch. Selva was transplanted through the plastic mulch one month later. Conventional practices for annual strawberry production and pest management for the area were followed, including sprinkler irrigation initially and drip irrigation in the production season. Berries were picked for fresh market at least weekly for several months by normal grower practice.

All of the bed fumigation treatments used in 4 years of experiments increased yield significantly in comparison to nonfumigated soil. For example, yields in 1997 and 1998, respectively, relative to those obtained following standard bed fumigation with methyl bromide/chloropicrin (67/33% @ 325 lb/acre), were 117 and 76% for chloropicrin alone (300 lb/acre), 105 and 87% for Telone/chloropicrin (65/35% @ 425 lb/acre), or 66 and 45% for nontreated soil. Application of the Telone/chloropicrin mixture to beds at the same rate in a water emulsion through drip lines gave yields of 102 and 104% relative to those obtained on beds fumigated with methyl bromide/chloropicrin, while broadcast fumigation with methyl bromide/chloropicrin (67/33%, 315-330 lb/acre total area) gave relative yields of 112 and 96%. All fumigation treatments reduced *V. dahliae* populations in soil and effectively controlled weed growth through plant holes in the plastic mulch. The results show that bed fumigations with the materials used can be effective and that drip application of emulsified Telone/chloropicrin shows promise, but the specific methods of application need further research. The use of a virtually impermeable black plastic mulch (Bromotec Y681B, Lawson Mardon Packaging, U.K.) in 1998 improved yields on average by 16% over those obtained with a standard black polyethylene mulch in the bed fumigation treatments above, and with chloropicrin or Telone/chloropicrin applied at rates reduced by one third.

Four experiments on a broccoli-strawberry rotation on nonfumigated soils have been completed. At Davis, CA, where *V. dahliae* is absent, one year of fallow or one year of broccoli production did not increase subsequent strawberry yields over those obtained with continuous strawberry production. Fumigation with methyl bromide/chloropicrin in the same experiment increased strawberry yields 54-69%. At the Watsonville site with high populations of *V. dahliae* present, a one-year rotation with broccoli increased subsequent strawberry yields by 24-38% and one year of rye increased yield 18-44%, relative to continuous strawberry, all on nonfumigated soil. Yield increases following one-year rotations out of strawberry, however, were approximately half as large as those obtained by soil fumigation in the same site and years. Although current California strawberry varieties are all susceptible to Verticillium wilt, the relationship of disease incidence to initial populations of *V. dahliae* in soil differed significantly between the varieties Selva and Camarosa.

We are researching microbiological differences associated with the enhanced growth and productivity of strawberries in soils fumigated with methyl bromide/chloropicrin where the response is not due to control of known, major pathogens. Plants in fumigated soils consistently had higher root length densities and fewer dark roots than plants in nonfumigated soils. Relative to nonfumigated soils, total numbers of fungi are usually low for several months following fumigation. *Cylindrocarpon* spp. were isolated from 0.5-cm segments of strawberry roots grown in nonfumigated soils (mean frequency 14%) but not from roots grown in fumigated soils. *Pythium* spp. were more commonly isolated from roots in nonfumigated soils. with mean isolation frequencies of 3 and 11% for fumigated and nonfumigated soils, respectively. *Rhizoctonia* spp. were frequently isolated from roots in both fumigated and nonfumigated soils. Pathogenicity of the predominant isolates of these fungi was tested on strawberry in the greenhouse. *Cylindrocarpon* spp. did not cause significant root rot. but some isolates caused significant reductions in shoot and root growth. *P. ultimum* caused root rot and growth reductions. Of the 14 binucleate isolates of *Rhizoctonia* spp. tested, four caused significant root rot and growth reductions, while three others caused only growth reductions. Total populations of bacteria in soil were not affected by fumigation, but fluorescent pseudomonads were significantly less 5 days after fumigation. Populations of fluorescent pseudomonads in soil, however, increased quickly following fumigation and were 10-1000 fold higher than in nonfumigated soils 10 days to 9 months after fumigation. Predominant isolates of fluorescent pseudomonads from the rhizosphere were tested for effects on strawberry growth in natural field soil in the greenhouse. The effects of individual isolates ranged from beneficial (increased shoot and root dry weights up to 72% and 162%, respectively) to deleterious (about 20% shoot or root reduction). *Pseudomonas fluorescens, P. putida* and *P. chlororaphis* were among the most predominant and beneficial rhizobacteria tested. The results suggest that reductions in deleterious fungi and increases in beneficial fluorescent pseudomonads contribute to the enhanced growth response of strawberry to soil fumigation with methyl bromide/chloropicrin.

Research currently in progress during the 1998-99 growing season includes the following:

1. Continued experiments on the microbial mechanisms by which strawberry growth and yield respond to soil fumigation, with further testing of potentially beneficial microorganisms.
2. A comparison of broadcast and bed fumigations, and further bed fumigation experiments on chloropicrin with and without Telone added. In cooperation with Husein Ajwa and Tom Trout, ARS-USDA, this includes the use of fumigants at relatively low rates, applied by shank injection or through drip lines as emulsions, and a comparison of standard polyethylene to a high-barrier plastic mulch.
3. Experiments on the possible use of ozone as a soil fumigant, both with and without the addition of beneficial microorganisms.
4. Experiments funded by the Statewide UC IPM Program on cultural management of Verticillium wilt in strawberry production, including crop rotations, organic soil amendments, determinations of inoculum thresholds for disease and yield losses, and development of improved methods to screen strawberry varieties for genetic tolerance or resistance to Verticillium wilt.

# A comparison of the weed control in strawberries resulting from bed fumigation with chloropicrin, Telone and methyl bromide.

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**Summary**

There is a general concern that the alternatives to methyl bromide are less efficacious on weeds than methyl bromide. The objective of this evaluation was to measure the weed control resulting from fumigation with chloropicrin, Telone and methyl bromide. At D&B Specialty Farms, Santa Maria. CA, treatments applied through the subsurface drip irrigation were chloropicrin EC at 14 and 24 GPA, Telone C35 EC at 21 and 35 GPA. Shank injection treatments were methyl bromide/chloropicrin at 300 lbs. per acre. An untreated check was also included. Each treatment was tarped with three types of plastic: black, clear virtually impermeable film, and clear standard tarp. Transplanting was completed on November 6, 1998 and the initial weed density counts, No. per 400 $in^2$, were made on November 11, 1998. Mean separation was performed using Fisher's protected LSD. Virtually impermeable film (VIF) improved the activity of Telone C35 EC at 21 GPA on filaree (Table 1). Over all fumigants the VIF improved the activity of all fumigants on filaree (Table 2). No fumigant or tarp effects on clover populations were detected.

**Table 1.** ANOVA by individual treatment.

| | Weed density (no. 400 $in.^2$) | | | |
|---|---|---|---|---|
| | Clover | | Filaree | |
| Treatment | Clear std. | VIF | Clear std. | VIF |
| 1. Chloropicrin 24 GPA | 2.7 ab | 3.5 ab | 1.0 abc | 1.3 ab |
| 2. Chloropicrin 14 GPA | 2.0 ab | 2.2 ab | 1.3 ab | 0.3 bc |
| 3. Telone C35 35 GPA | 5.7 a | 1.0 ab | 1.0 abc | 0.0 c |
| 4. Telone C35 21 GPA | 4.2 ab | 2.5 ab | 1.5 a | 0.2 c |
| 5. Nonfumigated | -- | -- | -- | -- |
| 6. M. bromide 300 lb/A | 4.5 ab | 0.2 b | 0.3 bc | 0.2 c |
| LSD 0.05 | 5.01 | | 1.05 | |

**Table 2.** Factorial analysis: main effect of tarp type.

| | Weed density (no. 400 $in.^2$) | |
|---|---|---|
| Tarp type | Clover | Filaree |
| Standard tarp | 3.8 | 1.0 a |
| VIF | 1.9 | 0.4 b |
| LSD 0.05 | 2.47 | 0.47 |

## Summary of Recent Research on Verticillium wilt in High Elevation Strawberry Nurseries

T.R. Gordon, Plant Pathology, U.C. Davis

K.D. Larson, Pomology Department, U.C. Davis

D.V. Shaw, Pomology Department, U.C. Davis

During 1998, research continued on the use of chemical fumigants and cover crops for control of Verticillium wilt, caused by *Verticillium dahliae*, in high elevation strawberry nurseries. Six treatments were tested in a field experiment, which was initiated in 1995; each treatment had three replications, for a total of 18 plots. In one of these treatments, plots were kept fallow, while the other five treatments all had fall crops of rye in 1995 and 1996. Treatment two included spring plantings of mustard (canola), in 1996 and 1997, following incorporation of the fall rye crop. The mustard crops were cut and incorporated in the summer, and tarped for approximately one month. Treatments three through five had two years in rye followed by a chemical fumigation in August of 1997: either methyl bromide:chloropicrin (2:1) @ 350 pounds/acre, chloropicrin alone @ 250 pounds/acre, or C-35 (35% chloropicrin and 65% telone) @ 380 pounds/acre. The last treatment had two years in rye and no fumigation.

In April of 1998, all plots were planted to two strawberry cultivars, Camarosa and Selva. All fumigation treatments appeared to be equally effective in reducing soil populations of *V. dahliae*, which were undetectable (< 1 microsclerotium/gram of soil) in all the fumigated plots. Of the non-fumigated treatments, fallow had the lowest levels of *V. dahliae* (11 microsclerotia/gram), whereas the rye only and the rye/mustard treatments both had an average of 20 microsclerotia/gram. No disease was detectable in any of the fumigated plots. For Camarosa, 52, 56, and 76% of the plants had symptoms of Verticillium wilt in the rye, fallow, and rye/mustard treatments, respectively. For Selva, in both the rye and rye/mustard treatments, 87% of the plants were symptomatic, whereas 73% of the plants in fallowed plots had disease symptoms.

In summary, all the chemical fumigants provided adequate control of Verticillium wilt; whereas none of the non-chemical treatments was satisfactory. It should also be noted that fumigation experiments in previous years have shown less complete control with non-methyl bromide treatments. Thus chloropicrin alone or combined with telone may prove to be less consistent than the standard methyl bromide:chloropicrin combination.

In terms of runner production in the nursery, methyl bromide: chloropicrin was the best treatment. For Selva, plots receiving this treatment produced an average of 1331 runners per plot. The C-35 treatment (1117 runners/plot) was not significantly different from methyl bromide:chlorpicrin but chloropicrin alone was significantly worse (920 runners/plot). Similar results were obtained for Camarosa, although in this case, the differences between the fumigants were not statistically significant. Overall, the results indicate that the fumigants differ somewhat due to factors other than Verticillium. That is, although Verticillium wilt was not a problem in any of the fumigated plots, there were differences in productivity. This may reflect the activity of microorganisms in the soil that were differentially affected by the fumigants.

Runners representative of each nursery treatment have been planted at the South Coast field station (Camarosa) and at Watsonville (Selva) in order to evaluate any carry-over effects of the nursery treatments. Previous findings suggest that plants from nursery plots fumigated with chloropicrin or C-35 will not perform as well as those from methyl bromide:chloropicrin fumigated ground.

During 1999 we will also be evaluating the effects of post-harvest chilling treatments on plants from a high elevation nursery. Results from last year indicated that extended chilling periods significantly reduced the survival of *Verticillium dahliae* in infected runner plants. For example, in Selva stored at 34 F for 32 days, the pathogen was virtually eliminated. As a result, based on the cumulative fruit yield, there was no difference between plants from fumigated nursery plots and those from the same plots, which were inoculated prior to planting (at the nursery). However, fruit production by plants from non-fumigated plots never reached the levels of the plants from fumigated nursery plots, even with maximum chilling. This indicates that carry-over effects resulting from factors other than Verticillium are not negated by exposure to low temperatures.

Comparable effects were not been observed for Camarosa, where chilling was correlated with only a modest reduction in the incidence of Verticillium. However, because Camarosa is typically planted soon after harvest. the longest chilling period we tested was 17 days. Currently we are looking at the effects of longer chilling periods in Camarosa, to determine if this explains the difference between the two varieties. Preliminary indications are that Verticillium levels remain high, even when Camarosa is stored for >30 days. Thus. varietal differences may be important as well. We are also testing the effects of a late nursery harvest of Camarosa, to coincide with Selva, to determine if this contributes to a difference in the effects of post-harvest chilling. To gain further insight into the influence of variety on the chilling response, we have included Diamante in our current year's experiment, to provide a day neutral variety for comparison with Selva.

# Pomology Progress Report, South Coast Field Day 1999: Cultural Practices

Kirk D. Larson and Douglas V. Shaw, Department of Pomology, U.C. Davis

**Chemical control of soil pathogens: Ridomil/Aliette trial results.** Severe *P. cactorum* induced plant collapse in the Diamante cultivar two years ago stimulated our interest in cultural methods of control. Metalaxyl (Ridomil) and various phosphorus acid products have been used in strawberry for years to mitigate these problems, although dispute is common over their effectiveness. Greenhouse experiments suggest little or no effectiveness of these compounds whereas growers and many nursery producers remain convinced. One possible explanation is that little effectiveness is realized when very severe infection of local soil is the issue. Conversely, with sufficient fumigation, most infection may be due to nursery origin rather than field infection. Preliminary results demonstrated substantial effectiveness of Alliette in decreasing plant collapse and increasing the yield of surviving plants, where the source of infection was nursery stock. Ridomil proved effective in reducing plant collapse, but also reduced the productivity of surviving plants. This previously unrecognized complementary activity in preventing collapse offset by stunting may explain the failure of past field experiments to demonstrate the effectiveness of Ridomil. Additional trials with these materials are planned.

**Root Pruning Trials.** Problems in establishing bare-root transplants are sometimes the result of improper planting: crowns planted too deep may suffer from root or crown rot, while crowns planted too high suffer from poor rooting, and poor growth and yield. A trial conducted last year demonstrated that there was no effect of root pruning on plant growth or yield, and that root pruning facilitated proper planting of transplants. Additional trials are in progress this year.

**1999 Fumigation Update.** Although domestic regulation provides for continued use of methyl bromide (MB) until 2005, alternatives research remain our project's top priority.

Variation in reported results due to statistical sampling and differences in the technical quality of research have generated a bewildering array of speculations about the effectiveness of MB and other materials. One way to mitigate these difficulties is to compile research summaries. The study set below contains over 45 studies conducted from 1987 to the present representing up to 7 major locations. What we know from this summary can be summarized as follows.

Without fumigation, yields drop an average of 37% in the first non-fumigated cycle, even in the absence of major pathogens. The yield drops further with each propagation cycle, perhaps leveling off at 50- 60%. In the 4th crop at Watsonville without fumigation (10 years since last fumigation, 1 fumigated crop, 3 NF crops and 5 cover crops intervening), the weeds are so bad that black plastic and herbicide application will be required hence forth. Fertilization and chilling treatments have been relatively ineffective in mitigating losses, major pathogens make things worse. These results do not include the negative aspects of using plants from non-fumigated nurseries, which exacerbates the lethal and non-specific soil pathogen problems.

Any fumigation alternative is better than none, but none are as effective as our current practice. Chloropicrin works reasonably well at high rates initially, but weakens on serial use. Growers are not likely to be permitted use of chloropicrin at the higher rates tested and moderate rates are considerably less effective, suffering rather serious yield losses and increased risk of lethal pathogen infestation. Telone-chloropicrin combinations work about as well as would be predicted from the rate of chloropicrin included, perhaps with some slight advantage over chloropicrin alone for control of lethal pathogens. A 300' buffer and a serious quantity use restriction will limit the utility of this compound as an alternative. Metam sodium has never worked well alone. some say it is inconsistent, our experience is that it is consistently substandard.

Our greatest success over the past 6 years has been with serial applications of chloropicrin and metam sodium. Results are substandard compared with current practices, this is definitely an expensive alternative. and technically more complicated. Technical drawbacks have also been observed due to planting through the tarp with day-neutral types. However, combined application is especially advantageous when only low rates of chloropicrin are permitted. This alternative also permits weed control sufficient to use clear polyethylene.

Our project also has conducted research to address the loss of methyl bromide in strawberry nurseries. and assure the continued quality or "fitness" of strawberry runner transplants. To this end, collaborative research with Dr. Tom Gordon resulted in the implementation and conclusion of a 3-year nursery crop rotation/soil fumigation trial. Results from this trial provided a 6th year of nursery productivity data for various MB alternatives, and demonstrated the ineffectiveness of crop rotation as a replacement for MB soil fumigation. Perhaps most importantly, Pomology nursery fumigation research has demonstrated that the loss of MB will impact strawberry nursery productivity, and that there is a significant "carry over" of nursery treatments into the fruiting field. Nursery fumigation research will continue in 1999 with a high-elevation nursery fumigation trial that was established this past fall.

# Evaluation of Drip Irrigation Systems to Deliver Alternative Fumigants to Methyl Bromide for Strawberry Production

Husein Ajwa and Tom Trout, USDA-ARS
Water Management Research Laboratory, Fresno, CA

**Objectives:** to determine the distribution and efficacy of Telone C35 EC, and chloropicrin applied through drip irrigation systems, and to develop optimum irrigation parameters for strawberry production under the alternative fumigants.

Variables that are being evaluated include fumigants, application rate, amount of water used to apply the fumigants, application of combinations of fumigants, number of drip lines with which to apply fumigants, and the affect of VIF tarps.

**Fumigants (Applied 9/28/98)**

High chloropicrin EC 24 gal/acre, Drip applied
Low chloropicrin EC 14 gal/acre, Drip applied
High Telone C35EC 35 gal/acre, Drip applied
Low Telone C35EC 21 gal/acre, Drip applied
Nonfumigated
MBr/Pic 300 lbs/acre, Shank applied

| | | |
|---|---|---|
| High Telone C35EC 35 gal/acre, Drip applied | | Black standard tarp |
| Low Telone C35EC 21 gal/acre, Drip applied | | Black standard tarp |
| Low Telone C35EC 21 gal/acre, Drip applied | | Clear standard tarp |
| High Telone C35EC 35 gal/acre, Drip applied | | Clear standard tarp |
| Low Telone C35EC 21 gal/acre, Drip applied | | Clear VIF |
| High Telone C35EC 35 gal/acre, Drip applied | | Clear VIF |
| MBr/Pic 300 lbs/acre, Shank applied | Nonfumigated | Clear VIF |
| High chloropicrin EC 24 gal/acre, Drip applied | | Clear VIF |
| Low chloropicrin EC 14 gal/acre, Drip applied | | Clear VIF |
| Nonfumigated | MBr/Pic 300 lbs/acre, Shank applied | Black standard tarp |
| High chloropicrin EC 24 gal/acre, Drip applied | | Black standard tarp |
| Low chloropicrin EC 14 gal/acre, Drip applied | | Black standard tarp |
| MBr/Pic 300 lbs/acre, Shank applied | Nonfumigated | Clear standard tarp |
| High chloropicrin EC 24 gal/acre, Drip applied | | Clear standard tarp |
| Low chloropicrin EC 14 gal/acre, Drip applied | | Clear standard tarp |

200'

# Evaluation of Drip Irrigation Systems to Deliver Alternative Fumigants to Methyl Bromide for Strawberry Production

Husein Ajwa and Tom Trout, USDA-ARS
Water Management Research Laboratory, Fresno, CA

**Objectives:** to determine the distribution and efficacy of Telone C35 EC, Vapam. and Chloropicrin applied through drip irrigation systems, and to develop optimum irrigation parameters for strawberry production under the alternative fumigants.

Variables that are being evaluated include fumigants application rate, amount of water used to apply the fumigants, and application of combinations of fumigants.

## FUMIGANT APPLICATION TREATMENTS

| Trt# | Treatment Description |
|---|---|
| 1 | Untreated control |
| 2 | MeBr/Chloropicrin bed shank injection @ 425 lb/ac (245 lb/ac-bed) |
| 3 | Telone/Chloropicrin (Telone C35) bed shank injection @ 425 lb/ac |
| 4 | Telone C35 EC drip applied @ 425 lb/ac in 15 mm net irrigation |
| 5 | Telone C35 EC drip applied @ 425 lb/ac in 25 mm net irrigation |
| 6 | Telone C35 EC drip applied @ 425 lb/ac in 35 mm net irrigation |
| 7 | Telone C35 EC drip applied @ 255 lb/ac in 25 mm net irrigation |
| 8 | Vapam (42%) drip applied @ 75 gal/ac in 25 mm net irrigation |
| 9 | Vapam (42%) drip applied @ 75 gal/ac in 35 mm net irrigation |
| 10 | Vapam (40%) drip applied @ 50 gal/ac in 25 mm net irrigation |
| 11 | Telone C35 EC @ 255 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 12 | Chloropicrin @ 160 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 13 | Chloropicrin ~ 160 lb/a~ drip applied in 25 mm net irrigation |

## IRRIGATION TREATMENTS

Strawberry yield in Telone C35 bed shank injection (at 425 lb/ac and 255 lb/ac) will be irrigated by three irrigation amounts [75% (Low), 100% (Med.), and 125% (High) of crop evapotranspiration].

MBA 1998-99

| | # | Irrig | | | | MBA 98 plots (Fumigated Sept 6-8, 1998) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | # | | | | | (T13)-PicMw (25 mm) | (T9)-MvHw (35 mm) | (T5)-HtMw (25 mm) | (T12)-(Pic+Mv)Mw |
| | 1 | M | Low Telone C35 Shank | High Telone C35 Shank | | (T7)-MtMw (25 mm) | (T8)-HvMw (25 mm) | (T10)-MvMw (25 mm) | (T2)-MeBr/Pic Shank |
| | 2 | L | [illegible] | High Telone C35 Shank | | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) | (T13)-PicMw (25 mm) | (T6)-HtHw (35 mm) |
| | 3 | H | Low Telone C35 shank | High Telone C35 Shank | | (T4)-HtLw (15 mm) | (T12)-(Pic+Mv)Mw | (T8)-HvMw (25 mm) | (T9)-MvHw (35 mm) |
| | 4 | H | High Telone C35 Shank | [illegible] | | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank | (T5)-HtMw (25 mm) |
| | 5 | M | High Telone C35 Shank | [illegible] | | (T11)-(Mt+Mv)Mw | (T1)-Untreated control | (T12)-(Pic+Mv)Mw | (T4)-HtLw (15 mm) |
| | 6 | L | High Telone C35 Shank | Low Telone C35 shank | | (T9)-MvHw (35 mm) | (T3)-Telone/Pic Shank | (T1)-Untreated control | (T11)-(Mt+Mv)Mw |
| | 7 | M | [illegible] | High Telone C35 Shank | | (T1)-Untreated control | (T4)-HtLw (15 mm) | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) |
| | 8 | H | [illegible] | High Telone C35 Shank | | (T5)-HtMw (25 mm) | (T13)-PicMw (25 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank |
| | 9 | L | [illegible] | High Telone C35 Shank | | (T12)-(Pic+Mv)Mw | (T2)-MeBr/Pic Shank | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) |
| | 10 | M | High Telone C35 Shank | [illegible] | | (T10)-MvMw (25 mm) | (T11)-(Mt+Mv)Mw | (T9)-MvHw (35 mm) | (T8)-HvMw (25 mm) |
| | 11 | L | High Telone C35 Shank | [illegible] | | (T3)-Telone/Pic Shank | (T6)-HtHw (35 mm) | (T11)-(Mt+Mv)Mw | (T1)-Untreated control |
| | 12 | H | High Telone C35 Shank | [illegible] | | (T8)-HvMw (25 mm) | (T5)-HtMw (25 mm) | (T4)-HtLw (15 mm) | (T13)-PicMw (25 mm) |
| | | | 35 ft | 35 ft | | 31 ft | 31 ft | 31 ft | 31 ft |

# Cultural and Genetic Strategies for Management of Phytophthora on California Strawberries

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## Background and Project Significance

Root or crown infections by *Phytophthora* species can cause plant stunting or collapse and reduce profitability of nursery and fruit production. The infections and disease development are favored by mild to moderate temperatures and periods of soil water saturation. *Phytophthora* species are soilborne, but they are spread readily by plants, soil, or water. Methyl bromide/chloropicrin mixtures effectively reduce populations of *Phytophthora*, but alternative management approaches will increase in importance as methyl bromide (MB) use is restricted.

## Highlights of 1997/98 work

**Field evaluations of resistance to Phytophthora.** The UC strawberry breeding program has adopted field screens for ongoing evaluations of genetic resistance to Verticillium wilt, but similar evaluations are just beginning for Phytophthora crown rot. We are developing the required screening methods and, at the same time, evaluating resistance of recently released California cultivars to *P. cactorum* and *P. citricola*. We intend to provide growers with replicated assessments of Phytophthora resistance on newly released strawberry cultivars and furnish breeders with reliable methods for future evaluations of Phytophthora resistance in their programs.

Last year at Monterey Bay Academy, soil infestation and plant dip inoculations were tested for use in the screens. Cultivar Pajaro was used as a susceptible standard and developed early-season stunting and late-season collapse when planted in holes infested with *P. cactorum* or *P. citricola*. Decreasing the amount of inoculum by 50% or moving it a few inches away from the plant crown reduced stunting and subsequent mortality. Plant dipping in liquid *Phytophthora* suspension provided a faster, simpler inoculation procedure than soil infestation, but results with the former have been less reliable to date.

The soil infestation procedure was applied to assess resistance of Aromas, Camarosa, Diamante, and Pajaro. *P. cactorum* caused significant early-season stunting in all four cultivars (Fig. 1-A), but as the season progressed, only Diamante and Pajaro suffered much mortality (Fig. 1-B). The marketable yields of Aromas and Camarosa in *P. cactorum* infested soil were 81% and 64% of their non-inoculated controls, whereas those of Diamante and Pajaro were only 35-36% of their controls, (Fig. 1-C). Overall, *P. citricola* was less damaging than *P. cactorum* on Diamante and Pajaro and did not reduce yields of Aromas (Fig. 1A-C). Additional experiments are underway in an experimental nursery area at the Wolfskill facility. We are determining if Phytophthora resistance screening can be accomplished there as well as at MBA.

**Greenhouse evaluations of resistance to *Phytophthora*.** In past years, greenhouse screens of resistance to *Phytophthora* have given mixed results when repeated at different times of the year. Our goals with greenhouse experiments are 1) to improve their reliability and 2) to test their validity against field results. Results of 1998 experiments on greenhouse screening methods indicated that:

- 24-hr weekly soil-water saturation periods caused twice as much damage as 48-hr biweekly wetting periods.
- 9- or 13-wk. periods were sufficient for crown rot development; a 5-wk. period was too short.
- Mineral or peat/sand potting media were similarly conducive to root and crown rot.
- Artificial pre-inoculation chilling did not influence susceptibility to Phytophthora crown rot.

- ♦ Plant dip inoculations worked as well as soil infestation inoculations.
- ♦ Pot size could be reduced without significantly affecting results.

**Irrigation-Phytophthora interactions at MBA.** Careful irrigation water management can aid control of many diseases caused by *Phytophthora*, because soil saturation favors dispersal and infection by *Phytophthora* spores. We are investigating the influence of irrigation intensity on development of Phytophthora crown rot. At MBA, the duration of every-other-day drip irrigations was varied during April-July so that amounts of water applied approximated 50%, 100%, or 200% of evapotranspiration (ET) demand in non-infested soil and soil infested with a *P. cactorum* + *P. citricola* mixture. In the infested plots, mortality was lowest and yield greatest under the 200% ET regime (Fig. 1-D). We suspect that high amounts of rainfall last year favored early-season infection by Phytophthora before differential irrigation was imposed. Slight water stress under the "0.5 ET" irrigation regime may have hastened collapse of already-infected plants. We are repeating the work this year.

**Future directions**

The overall goal is to develop and facilitate cultural, genetic, and chemical strategies for management of Phytophthora diseases on California strawberries. These strategies, along with similar ones for other soilborne disease complexes, should help lessen dependence upon methyl bromide fumigation. Work in progress includes:

- ♦ Enlarged field screening tests for Phytophthora resistance at MBA with cultivars Aromas, Camarosa. Diamante, Gaviota, Pacific, Pajaro, and Parker (last two used as standards).
- ♦ Evaluation of a Phytophthora resistance screening protocol at Wolfskill for the UC strawberry program.
- ♦ Determining the degree of agreement between field and greenhouse assessments of resistance to *Phytophthora.*
- ♦ Determining effects of irrigation intensity on development of Phytophthora crown rot.
- ♦ Determining efficacy of Ridomil Gold EC and Aliette WDG for control of Phytophthora crown rot (field experiment at MBA).

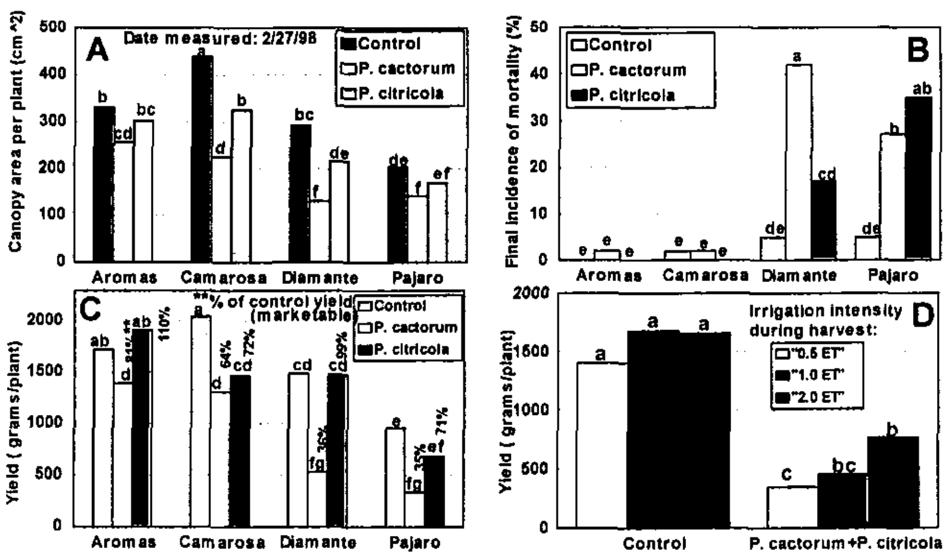


**Figure 1.** Relative susceptibility of some strawberry cultivars to: **A**, early season stunting; **B**, plant mortality, and **C**, yield depression caused by *Phytophthora cactorum* and *P. citricola.* **D**, effects of *P. cactorm* + *P. citricola* and irrigation intensity during harvest on total marketable fruit yield of cultivar Diamante.

# Response of Strawberry to Soil Fumigation: Microbial Mechanisms and some Alternatives to Methyl Bromide

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The experiments reported here are part of a larger project supported by the California Strawberry Commission and ARS-USDA to research chemical and nonchemical alternatives to methyl bromide for preplant fumigation of soil in strawberry production. Chemical alternatives to methyl bromide have been tested in replicated field experiments at the Monterey Bay Academy near Watsonville, CA. Strawberry was grown every year, *Verticillium dahliae* was present in the soil, and bed fumigation treatments were applied in early October of each year. Two-row beds were shaped, fumigated (two shanks/bed, 15-20 cm deep, rates given per unit of treated bed area, which is 58% of the total area), and covered with black plastic mulch. Selva was transplanted through the plastic mulch one month later. Conventional practices for annual strawberry production and pest management for the area were followed, including sprinkler irrigation initially and drip irrigation in the production season. Berries were picked for fresh market at least weekly for several months by normal grower practice.

All of the bed fumigation treatments used in 4 years of experiments increased yield significantly in comparison to nonfumigated soil. For example, yields in 1997 and 1998, respectively, relative to those obtained following standard bed fumigation with methyl bromide/chloropicrin (67/33% @ 325 lb/acre), were 117 and 76% for chloropicrin alone (300 lb/acre), 105 and 87% for Telone/chloropicrin (65/35% @ 425 lb/acre), or 66 and 45% for nontreated soil. Application of the Telone/chloropicrin mixture to beds at the same rate in a water emulsion through drip lines gave yields of 102 and 104% relative to those obtained on beds fumigated with methyl bromide/chloropicrin, while broadcast fumigation with methyl bromide/chloropicrin (67/33%, 315-330 lb/acre total area) gave relative yields of 112 and 96%. All fumigation treatments reduced *V. dahliae* populations in soil and effectively controlled weed growth through plant holes in the plastic mulch. The results show that bed fumigations with the materials used can be effective and that drip application of emulsified Telone/chloropicrin shows promise, but the specific methods of application need further research. The use of a virtually impermeable black plastic mulch (Bromotec Y681B, Lawson Mardon Packaging, U.K.) in 1998 improved yields on average by 16% over those obtained with a standard black polyethylene mulch in the bed fumigation treatments above, and with chloropicrin or Telone/chloropicrin applied at rates reduced by one third.

Four experiments on a broccoli-strawberry rotation on nonfumigated soils have been completed. At Davis, CA, where *V. dahliae* is absent, one year of fallow or one year of broccoli production did not increase subsequent strawberry yields over those obtained with continuous strawberry production. Fumigation with methyl bromide/chloropicrin in the same experiment increased strawberry yields 54-69%. At the Watsonville site with high populations of *V. dahliae* present, a one-year rotation with broccoli increased subsequent strawberry yields by 24-38% and one year of rye increased yield 18-44%, relative to continuous strawberry, all on nonfumigated soil. Yield increases following one-year rotations out of strawberry, however, were approximately half as large as those obtained by soil fumigation in the same site and years. Although current California strawberry varieties are all susceptible to Verticillium wilt, the relationship of disease incidence to initial populations of *V. dahliae* in soil differed significantly between the varieties Selva and Camarosa.

We are researching microbiological differences associated with the enhanced growth and productivity of strawberries in soils fumigated with methyl bromide/chloropicrin where the response is not due to control of known, major pathogens. Plants in fumigated soils consistently had higher root length densities and fewer dark roots than plants in nonfumigated soils. Relative to nonfumigated soils, total numbers of fungi are usually low for several months following fumigation. *Cylindrocarpon* spp. were isolated from 0.5-cm segments of strawberry roots grown in nonfumigated soils (mean frequency 14%) but not from roots grown in fumigated soils. *Pythium* spp. were more commonly isolated from roots in nonfumigated soils, with mean isolation

frequencies of 3 and 11% for fumigated and nonfumigated soils, respectively. *Rhizoctonia* spp. were frequently isolated from roots in both fumigated and nonfumigated soils. Pathogenicity of the predominant isolates of these fungi was tested on strawberry in the greenhouse. *Cylindrocarpon* spp. did not cause significant root rot, but some isolates caused significant reductions in shoot and root growth. *P. ultimum* caused root rot and growth reductions. Of the 14 binucleate isolates of *Rhizoctonia* spp. tested, four caused significant root rot and growth reductions, while three others caused only growth reductions. Total populations of bacteria in soil were not affected by fumigation, but fluorescent pseudomonads were significantly less 5 days after fumigation. Populations of fluorescent pseudomonads in soil, however, increased quickly following fumigation and were 10-1000 fold higher than in nonfumigated soils 10 days to 9 months after fumigation. Predominant isolates of fluorescent pseudomonads from the rhizosphere were tested for effects on strawberry growth in natural field soil in the greenhouse. The effects of individual isolates ranged from beneficial (increased shoot and root dry weights up to 72% and 162%, respectively) to deleterious (about 20% shoot or root reduction). *Pseudomonas fluorescens, P. putida* and *P. chlororaphis* were among the most predominant and beneficial rhizobacteria tested. The results suggest that reductions in deleterious fungi and increases in beneficial fluorescent pseudomonads contribute to the enhanced growth response of strawberry to soil fumigation with methyl bromide/chloropicrin.

Research currently in progress during the 1998-99 growing season includes the following:

1. Continued experiments on the microbial mechanisms by which strawberry growth and yield respond to soil fumigation, with further testing of potentially beneficial microorganisms.
2. A comparison of broadcast and bed fumigations, and further bed fumigation experiments on chloropicrin with and without Telone added. In cooperation with Husein Ajwa and Tom Trout, ARS-USDA, this includes the use of fumigants at relatively low rates, applied by shank injection or through drip lines as emulsions, and a comparison of standard polyethylene to a high-barrier plastic mulch.
3. Experiments on the possible use of ozone as a soil fumigant, both with and without the addition of beneficial microorganisms.
4. Experiments funded by the Statewide UC IPM Program on cultural management of Verticillium wilt in strawberry production, including crop rotations, organic soil amendments, determinations of inoculum thresholds for disease and yield losses, and development of improved methods to screen strawberry varieties for genetic tolerance or resistance to Verticillium wilt.

# A comparison of the weed control in strawberries resulting from bed fumigation with chloropicrin, Telone and methyl bromide.

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**Summary**
There is a general concern that the alternatives to methyl bromide are less efficacious on weeds than methyl bromide. The objective of this evaluation was to measure the weed control resulting from fumigation with chloropicrin, Telone and methyl bromide. At D&B Specialty Farms, Santa Maria, CA, treatments applied through the subsurface drip irrigation were chloropicrin EC at 14 and 24 GPA, Telone C35 EC at 21 and 35 GPA. Shank injection treatments were methyl bromide/chloropicrin at 300 lbs. per acre. An untreated check was also included. Each treatment was tarped with three types of plastic: black, clear virtually impermeable film, and clear standard tarp. Transplanting was completed on November 6, 1998 and the initial weed density counts, No. per 400 in$^2$, were made on November 11, 1998. Mean separation was performed using Fisher's protected LSD. Virtually impermeable film (VIF) improved the activity of Telone C35 EC at 21 GPA on filaree (Table 1). Over all fumigants the VIF improved the activity of all fumigants on filaree (Table 2). No fumigant or tarp effects on clover populations were detected.

**Table 1.** ANOVA by individual treatment.

| | Weed density (no. 400 in.$^2$) | | | |
|---|---|---|---|---|
| | Clover | | Filaree | |
| Treatment | Clear std. | VIF | Clear std. | VIF |
| 1. Chloropicrin 24 GPA | 2.7 ab | 3.5 ab | 1.0 abc | 1.3 ab |
| 2. Chloropicrin 14 GPA | 2.0 ab | 2.2 ab | 1.3 ab | 0.3 bc |
| 3. Telone C35 35 GPA | 5.7 a | 1.0 ab | 1.0 abc | 0.0 c |
| 4. Telone C35 21 GPA | 4.2 ab | 2.5 ab | 1.5 a | 0.2 c |
| 5. Nonfumigated | -- | -- | -- | -- |
| 6. M. bromide 300 lb/A | 4.5 ab | 0.2 b | 0.3 bc | 0.2 c |
| LSD 0.05 | 5.01 | | 1.05 | |

**Table 2.** Factorial analysis: main effect of tarp type.

| | Weed density (no. 400 in.$^2$) | |
|---|---|---|
| Tarp type | Clover | Filaree |
| Standard tarp | 3.8 | 1.0 a |
| VIF | 1.9 | 0.4 b |
| LSD 0.05 | 2.47 | 0.47 |

## Summary of Recent Research on Verticillium wilt in High Elevation Strawberry Nurseries


| | | |
|---|---|---|
| T.R. Gordon | K.D. Larson | D.V. Shaw |
| Plant Pathology | Pomology Department | Pomology Department |
| U.C. Davis | U.C. Davis | U.C. Davis |


During 1998, research continued on the use of chemical fumigants and cover crops for control of Verticillium wilt, caused by *Verticillium dahliae*, in high elevation strawberry nurseries. Six treatments were tested in a field experiment, which was initiated in 1995; each treatment had three replications, for a total of 18 plots. In one of these treatments, plots were kept fallow, while the other five treatments all had fall crops of rye in 1995 and 1996. Treatment two included spring plantings of mustard (canola), in 1996 and 1997, following incorporation of the fall rye crop. The mustard crops were cut and incorporated in the summer, and tarped for approximately one month. Treatments three through five had two years in rye followed by a chemical fumigation in August of 1997: either methyl bromide:chloropicrin (2:1) @ 350 pounds/acre, chloropicrin alone @ 250 pounds/acre, or C-35 (35% chloropicrin and 65% telone) @ 380 pounds/acre. The last treatment had two years in rye and no fumigation.

In April of 1998, all plots were planted to two strawberry cultivars, Camarosa and Selva. All fumigation treatments appeared to be equally effective in reducing soil populations of *V. dahliae*, which were undetectable (< 1 microsclerotium/gram of soil) in all the fumigated plots. Of the non-fumigated treatments, fallow had the lowest levels of *V. dahliae* (11 microsclerotia/gram), whereas the rye only and the rye/mustard treatments both had an average of 20 microsclerotia/gram. No disease was detectable in any of the fumigated plots. For Camarosa, 52, 56, and 76% of the plants had symptoms of Verticillium wilt in the rye, fallow, and rye/mustard treatments, respectively. For Selva, in both the rye and rye/mustard treatments, 87% of the plants were symptomatic, whereas 73% of the plants in fallowed plots had disease symptoms.

In summary, all the chemical fumigants provided adequate control of Verticillium wilt; whereas none of the non-chemical treatments was satisfactory. It should also be noted that fumigation experiments in previous years have shown less complete control with non-methyl bromide treatments. Thus chloropicrin alone or combined with telone may prove to be less consistent than the standard methyl bromide:chloropicrin combination.

In terms of runner production in the nursery, methyl bromide: chloropicrin was the best treatment. For Selva, plots receiving this treatment produced an average of 1331 runners per plot. The C-35 treatment (1117 runners/plot) was not significantly different from methyl bromide:chlorpicrin but chloropicrin alone was significantly worse (920 runners/plot). Similar results were obtained for Camarosa, although in this case, the differences between the fumigants were not statistically significant. Overall, the results indicate that the fumigants differ somewhat due to factors other than Verticillium. That is, although Verticillium wilt was not a problem in any of the fumigated plots, there were differences in productivity. This may reflect the activity of microorganisms in the soil that were differentially affected by the fumigants.

Runners representative of each nursery treatment have been planted at the South Coast field station (Camarosa) and at Watsonville (Selva) in order to evaluate any carry-over effects of the nursery treatments. Previous findings suggest that plants from nursery plots fumigated with chloropicrin or C-35 will not perform as well as those from methyl bromide:chloropicrin fumigated ground.

During 1999 we will also be evaluating the effects of post-harvest chilling treatments on plants from a high elevation nursery. Results from last year indicated that extended chilling periods significantly reduced the survival of *Verticillium dahliae* in infected runner plants. For example, in Selva stored at 34 F for 32 days, the pathogen was virtually eliminated. As a result, based on the cumulative fruit yield, there was no difference between plants from fumigated nursery plots and those from the same plots, which were inoculated prior to planting (at the nursery). However, fruit production by plants from non-fumigated plots never reached the levels of the plants from fumigated nursery plots, even with maximum chilling. This indicates that carry-over effects resulting from factors other than Verticillium are not negated by exposure to low temperatures.

Comparable effects were not been observed for Camarosa, where chilling was correlated with only a modest reduction in the incidence of Verticillium. However, because Camarosa is typically planted soon after harvest, the longest chilling period we tested was 17 days. Currently we are looking at the effects of longer chilling periods in Camarosa, to determine if this explains the difference between the two varieties. Preliminary indications are that Verticillium levels remain high, even when Camarosa is stored for >30 days. Thus, varietal differences may be important as well. We are also testing the effects of a late nursery harvest of Camarosa, to coincide with Selva, to determine if this contributes to a difference in the effects of post-harvest chilling. To gain further insight into the influence of variety on the chilling response, we have included Diamante in our current year's experiment, to provide a day neutral variety for comparison with Selva.

# Pomology Progress Report, South Coast Field Day 1999: Cultivar Improvement

Douglas V. Shaw and Kirk D. Larson, Department of Pomology, U.C. Davis

**U.C. Strawberry Breeding Program Overview.** The northern and southern California breeding programs have diverged in recent years due to the distinct varietal needs of the south coast and central coast production regions. As the two breeding programs have diverged, activities in both locations have increased. In 1998 over 10,000 seedlings were grown and evaluated at each location and over 500 new selections were entered into first stage of advanced testing. Program divergence has mandated two high- elevation nursery programs, with over 100 accession/harvest date combinations in 1998.

**Cultivars released in 1997.** There appears to be general acceptance of most of the recent UC releases. Extrapolation from estimated nursery acreage suggests that about 2,000 acres of Diamante, Aromas, and Gaviota will be in production in 1999, and that this acreage was limited by plant supply. The strengths and weaknesses of each cultivar on commercial scales appear about as expected from small plot research. Botrytis and color problems with Diamante were greater in 1998 than in the past, but only on the coast, and likely due in part to excessive wet conditions; good yields and excellent fruit quality were obtained inland. Due to its productivity and color, interest in Aromas is greater on the coast where Diamante problems were most obvious. A 4-year summary suggested that Camarosa outyields Gaviota in Watsonville, at least on a per-plant basis. Gaviota would need more plants per acre to be directly competitive; a decrease from 16" to 14" at 52" centers would suffice. Gaviota performed better in Santa Maria, out-yielding Camarosa substantially in 1998, due largely to its rain tolerance.

**Advanced selections.** Several of the 1994 selections from the Watsonville program have shown promise in two years of testing. The most advanced and the most exciting items are short day types intended as replacements for Camarosa from Santa Maria and north. Specific objectives are a plant that can be planted later and maintains a more compact plant form, has later initiation of production to avoid spring rain, suffers fewer disease problems, and has a lower cull rate to enhance harvest efficiency. Item 94.3-11 is very promising; it out-yielded Camarosa over two years with a smaller plant and lower cull rate. Item 94.3-10 has exceptional flavor, but may have too low yield to be directly competitive with Camarosa. Item 94.19-5 has exceptionally large fruit and a compact plant. No releases are expected in 1999, the earliest point at which a final decision on these items would be made is September 2000.

Promising selections from the South Coast program include a high-yielding item (94.256-607) with Verticillium wilt tolerance that is in a grower trial in Santa Maria, and more than one dozen 1996 selections that are in grower tests throughout the state. For southern California, breeding objectives include adaptation to early nursery digging, early fruit production, sustained yields throughout the winter and spring, a low cull rate, and environmental tolerance.

**Resistance Breeding.** Considerable effort has been invested in the development of superior germplasm with resistance/tolerance to Verticillium wilt and two-spotted mites. A collaborative project with Drs. Doug Gubler and Tom Gordon has established testing for Verticillium wilt resistance as a standard procedure in the evaluation of parental stock and advanced selections. Similarly, collaborative work with Dr. Frank Zalom has resulted in extensive information regarding germplasm tolerance/susceptibility to two-spotted mite injury. Most recently, collaborative work with Dr. Greg Browne was initiated with the intent to develop similar resistance evaluation efforts for Phytophthora root/crown rot.

# Pomology Progress Report, South Coast Field Day 1999: Cultural Practices

Kirk D. Larson and Douglas V. Shaw, Department of Pomology, U.C. Davis

**Chemical control of soil pathogens: Ridomil/Aliette trial results.** Severe *P. cactorum* induced plant collapse in the Diamante cultivar two years ago stimulated our interest in cultural methods of control. Metalaxyl (Ridomil) and various phosphorus acid products have been used in strawberry for years to mitigate these problems, although dispute is common over their effectiveness. Greenhouse experiments suggest little or no effectiveness of these compounds whereas growers and many nursery producers remain convinced. One possible explanation is that little effectiveness is realized when very severe infection of local soil is the issue. Conversely, with sufficient fumigation, most infection may be due to nursery origin rather than field infection. Preliminary results demonstrated substantial effectiveness of Alliette in decreasing plant collapse and increasing the yield of surviving plants, where the source of infection was nursery stock. Ridomil proved effective in reducing plant collapse, but also reduced the productivity of surviving plants. This previously unrecognized complementary activity in preventing collapse offset by stunting may explain the failure of past field experiments to demonstrate the effectiveness of Ridomil. Additional trials with these materials are planned.

**Root Pruning Trials.** Problems in establishing bare-root transplants are sometimes the result of improper planting: crowns planted too deep may suffer from root or crown rot, while crowns planted too high suffer from poor rooting, and poor growth and yield. A trial conducted last year demonstrated that there was no effect of root pruning on plant growth or yield, and that root pruning facilitated proper planting of transplants. Additional trials are in progress this year.

***1999 Fumigation Update.*** Although domestic regulation provides for continued use of methyl bromide (MB) until 2005, alternatives research remain our project's top priority.

Variation in reported results due to statistical sampling and differences in the technical quality of research have generated a bewildering array of speculations about the effectiveness of MB and other materials. One way to mitigate these difficulties is to compile research summaries. The study set below contains over 45 studies conducted from 1987 to the present representing up to 7 major locations. What we know from this summary can be summarized as follows.

Without fumigation, yields drop an average of 37% in the first non-fumigated cycle, even in the absence of major pathogens. The yield drops further with each propagation cycle, perhaps leveling off at 50- 60%. In the 4th crop at Watsonville without fumigation (10 years since last fumigation, 1 fumigated crop, 3 NF crops and 5 cover crops intervening), the weeds are so bad that black plastic and herbicide application will be required hence forth. Fertilization and chilling treatments have been relatively ineffective in mitigating losses, major pathogens make things worse. These results do not include the negative aspects of using plants from non-fumigated nurseries, which exacerbates the lethal and non-specific soil pathogen problems.

Any fumigation alternative is better than none, but none are as effective as our current practice. Chloropicrin works reasonably well at high rates initially, but weakens on serial use. Growers are not likely to be permitted use of chloropicrin at the higher rates tested and moderate rates are considerably less effective, suffering rather serious yield losses and increased risk of lethal pathogen infestation. Telone-chloropicrin combinations work about as well as would be predicted from the rate of chloropicrin included, perhaps with some slight advantage over chloropicrin alone for control of lethal pathogens. A 300' buffer and a serious quantity use restriction will limit the utility of this compound as an alternative. Metam sodium has never worked well alone, some say it is inconsistent, our experience is that it is consistently substandard.

Our greatest success over the past 6 years has been with serial applications of chloropicrin and metam sodium. Results are substandard compared with current practices, this is definitely an expensive alternative, and technically more complicated. Technical drawbacks have also been observed due to planting through the tarp with day-neutral types. However, combined application is especially advantageous when only low rates of chloropicrin are permitted. This alternative also permits weed control sufficient to use clear polyethylene.

Our project also has conducted research to address the loss of methyl bromide in strawberry nurseries, and assure the continued quality or "fitness" of strawberry runner transplants. To this end, collaborative research with Dr. Tom Gordon resulted in the implementation and conclusion of a 3-year nursery crop rotation/soil fumigation trial. Results from this trial provided a 6th year of nursery productivity data for various MB alternatives, and demonstrated the ineffectiveness of crop rotation as a replacement for MB soil fumigation. Perhaps most importantly, Pomology nursery fumigation research has demonstrated that the loss of MB will impact strawberry nursery productivity, and that there is a significant "carry over" of nursery treatments into the fruiting field. Nursery fumigation research will continue in 1999 with a high-elevation nursery fumigation trial that was established this past fall.

# Evaluation of Drip Irrigation Systems to Deliver Alternative Fumigants to Methyl Bromide for Strawberry Production

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**Objectives:** to determine the distribution and efficacy of Telone C35 EC, Vapam, and Chloropicrin applied through drip irrigation systems, and to develop optimum irrigation parameters for strawberry production under the alternative fumigants.

Variables that are being evaluated include fumigants application rate, amount of water used to apply the fumigants, and application of combinations of fumigants.

## FUMIGANT APPLICATION TREATMENTS

| Trt# | Treatment Description |
|---|---|
| 1 | Untreated control |
| 2 | MeBr/Chloropicrin bed shank injection @ 425 lb/ac (245 lb/ac-bed) |
| 3 | Telone/Chloropicrin (Telone C35) bed shank injection @ 425 lb/ac |
| 4 | Telone C35 EC drip applied @ 425 lb/ac in 15 mm net irrigation |
| 5 | Telone C35 EC drip applied @ 425 lb/ac in 25 mm net irrigation |
| 6 | Telone C35 EC drip applied @ 425 lb/ac in 35 mm net irrigation |
| 7 | Telone C35 EC drip applied @ 255 lb/ac in 25 mm net irrigation |
| 8 | Vapam (42%) drip applied @ 75 gal/ac in 25 mm net irrigation |
| 9 | Vapam (42%) drip applied @ 75 gal/ac in 35 mm net irrigation |
| 10 | Vapam (40%) drip applied @ 50 gal/ac in 25 mm net irrigation |
| 11 | Telone C35 EC @ 255 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 12 | Chloropicrin @ 160 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 13 | Chloropicrin ~ 160 lb/a~ drip applied in 25 mm net irrigation |

## IRRIGATION TREATMENTS

Strawberry yield in Telone C35 bed shank injection (at 425 lb/ac and 255 lb/ac) will be irrigated by three irrigation amounts [75% (Low), 100% (Med.), and 125% (High) of crop evapotranspiration].

MBA 1998-99

| # | Irrig | | | | MBA 98 plots (Fumigated Sept 6-8, 1998) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | (T13)-PicMw (25 mm) | (T9)-MvHw (35 mm) | (T5)-HtMw (25 mm) | (T12)-(Pic+Mv)Mw |
| 1 | M | Low Telone C35 shank | High Telone C35 Shank | | (T7)-MtMw (25 mm) | (T8)-HvMw (25 mm) | (T10)-MvMw (25 mm) | (T2)-MeBr/Pic Shank |
| 2 | L | Low Telone C35 Shank | High Telone C35 Shank | | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) | (T13)-PicMw (25 mm) | (T6)-HtHw (35 mm) |
| 3 | H | Low Telone C35 shank | High Telone C35 Shank | | (T4)-HtLw (15 mm) | (T12)-(Pic+Mv)Mw | (T8)-HvMw (25 mm) | (T9)-MvHw (35 mm) |
| 4 | H | High Telone C35 Shank | Low Telone C35 Shank | | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank | (T5)-HtMw (25 mm) |
| 5 | M | High Telone C35 Shank | Low Telone C35 Shank | | (T11)-(Mt+Mv)Mw | (T1)-Untreated control | (T12)-(Pic+Mv)Mw | (T4)-HtLw (15 mm) |
| 6 | L | High Telone C35 Shank | Low Telone C35 Shank | | (T9)-MvHw (35 mm) | (T3)-Telone/Pic Shank | (T1)-Untreated control | (T11)-(Mt+Mv)Mw |
| 7 | M | Low Telone C35 Shank | High Telone C35 Shank | | (T1)-Untreated control | (T4)-HtLw (15 mm) | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) |
| 8 | H | Low Telone C35 Shank | High Telone C35 Shank | | (T5)-HtMw (25 mm) | (T13)-PicMw (25 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank |
| 9 | L | Low Telone C35 Shank | High Telone C35 Shank | | (T12)-(Pic+Mv)Mw | (T2)-MeBr/Pic Shank | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) |
| 10 | M | High Telone C35 Shank | Low Telone C35 Shank | | (T10)-MvMw (25 mm) | (T11)-(Mt+Mv)Mw | (T9)-MvHw (35 mm) | (T8)-HvMw (25 mm) |
| 11 | L | High Telone C35 Shank | Low Telone C35 Shank | | (T3)-Telone/Pic Shank | (T6)-HtHw (35 mm) | (T11)-(Mt+Mv)Mw | (T1)-Untreated control |
| 12 | H | High Telone C35 Shank | Low Telone C35 Shank | | (T8)-HvMw (25 mm) | (T5)-HtMw (25 mm) | (T4)-HtLw (15 mm) | (T13)-PicMw (25 mm) |
| | | 35 ft | 35 ft | | 31 ft | 31 ft | 31 ft | 31 ft |

# Cultural and Genetic Strategies for Management of Phytophthora on California Strawberries

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## Background and Project Significance

Root or crown infections by *Phytophthora* species can cause plant stunting or collapse and reduce profitability of nursery and fruit production. The infections and disease development are favored by mild to moderate temperatures and periods of soil water saturation. *Phytophthora* species are soilborne, but they are spread readily by plants, soil, or water. Methyl bromide/chloropicrin mixtures effectively reduce populations of *Phytophthora*, but alternative management approaches will increase in importance as methyl bromide (MB) use is restricted.

## Highlights of 1997/98 work

**Field evaluations of resistance to Phytophthora.** The UC strawberry breeding program has adopted field screens for ongoing evaluations of genetic resistance to Verticillium wilt, but similar evaluations are just beginning for Phytophthora crown rot. We are developing the required screening methods and, at the same time, evaluating resistance of recently released California cultivars to *P. cactorum* and *P. citricola*. We intend to provide growers with replicated assessments of Phytophthora resistance on newly released strawberry cultivars and furnish breeders with reliable methods for future evaluations of Phytophthora resistance in their programs.

Last year at Monterey Bay Academy, soil infestation and plant dip inoculations were tested for use in the screens. Cultivar Pajaro was used as a susceptible standard and developed early-season stunting and late-season collapse when planted in holes infested with *P. cactorum* or *P. citricola*. Decreasing the amount of inoculum by 50% or moving it a few inches away from the plant crown reduced stunting and subsequent mortality. Plant dipping in liquid *Phytophthora* suspension provided a faster, simpler inoculation procedure than soil infestation, but results with the former have been less reliable to date.

The soil infestation procedure was applied to assess resistance of Aromas, Camarosa, Diamante, and Pajaro. *P. cactorum* caused significant early-season stunting in all four cultivars (Fig. 1-A), but as the season progressed, only Diamante and Pajaro suffered much mortality (Fig. 1-B). The marketable yields of Aromas and Camarosa in *P. cactorum* infested soil were 81% and 64% of their non-inoculated controls, whereas those of Diamante and Pajaro were only 35-36% of their controls, (Fig. 1-C). Overall, *P. citricola* was less damaging than *P. cactorum* on Diamante and Pajaro and did not reduce yields of Aromas (Fig. 1A-C). Additional experiments are underway in an experimental nursery area at the Wolfskill facility. We are determining if Phytophthora resistance screening can be accomplished there as well as at MBA.

**Greenhouse evaluations of resistance to *Phytophthora*.** In past years, greenhouse screens of resistance to *Phytophthora* have given mixed results when repeated at different times of the year. Our goals with greenhouse experiments are 1) to improve their reliability and 2) to test their validity against field results. Results of 1998 experiments on greenhouse screening methods indicated that:

- 24-hr weekly soil-water saturation periods caused twice as much damage as 48-hr biweekly wetting periods.
- 9- or 13-wk. periods were sufficient for crown rot development; a 5-wk. period was too short.
- Mineral or peat/sand potting media were similarly conducive to root and crown rot.
- Artificial pre-inoculation chilling did not influence susceptibility to Phytophthora crown rot.

- ♦ Plant dip inoculations worked as well as soil infestation inoculations.
- ♦ Pot size could be reduced without significantly affecting results.

**Irrigation-Phytophthora interactions at MBA.** Careful irrigation water management can aid control of many diseases caused by *Phytophthora,* because soil saturation favors dispersal and infection by *Phytophthora* spores. We are investigating the influence of irrigation intensity on development of Phytophthora crown rot. At MBA, the duration of every-other-day drip irrigations was varied during April-July so that amounts of water applied approximated 50%, 100%, or 200% of evapotranspiration (ET) demand in non-infested soil and soil infested with a *P. cactorum* + *P. citricola* mixture. In the infested plots, mortality was lowest and yield greatest under the 200% ET regime (Fig. 1-D). We suspect that high amounts of rainfall last year favored early-season infection by Phytophthora before differential irrigation was imposed. Slight water stress under the "0.5 ET" irrigation regime may have hastened collapse of already-infected plants. We are repeating the work this year.

## Future directions

The overall goal is to develop and facilitate cultural, genetic, and chemical strategies for management of Phytophthora diseases on California strawberries. These strategies, along with similar ones for other soilborne disease complexes, should help lessen dependence upon methyl bromide fumigation. Work in progress includes:

- ♦ Enlarged field screening tests for Phytophthora resistance at MBA with cultivars Aromas, Camarosa, Diamante, Gaviota, Pacific, Pajaro, and Parker (last two used as standards).
- ♦ Evaluation of a Phytophthora resistance screening protocol at Wolfskill for the UC strawberry program.
- ♦ Determining the degree of agreement between field and greenhouse assessments of resistance to *Phytophthora.*
- Determining effects of irrigation intensity on development of Phytophthora crown rot.
- Determining efficacy of Ridomil Gold EC and Aliette WDG for control of Phytophthora crown rot (field experiment at MBA).

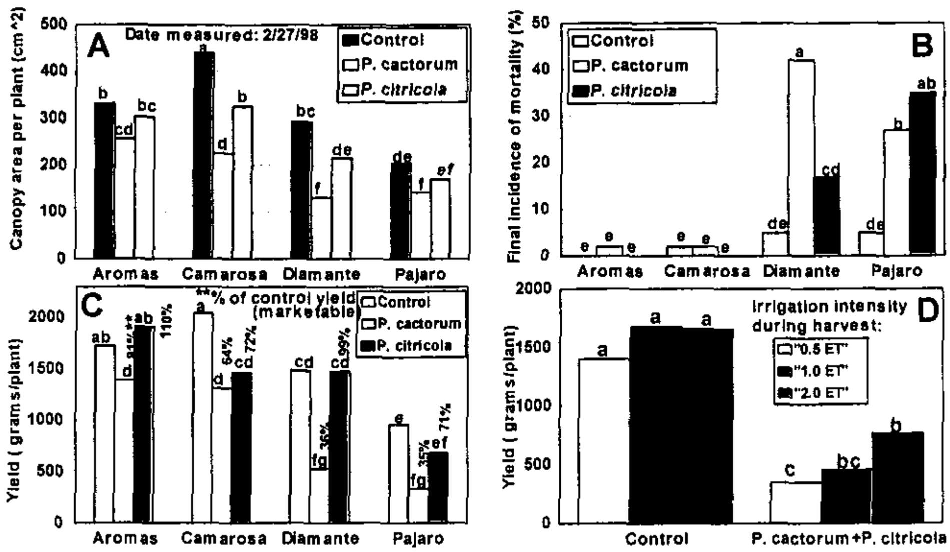


**Figure 1.** Relative susceptibility of some strawberry cultivars to: **A**, early season stunting; **B**, plant mortality, and **C**, yield depression caused by *Phytophthora cactorum* and *P. citricola.* **D**, effects of *P. cactorm* + *P. citricola* and irrigation intensity during harvest on total marketable fruit yield of cultivar Diamante.

# Response of Strawberry to Soil Fumigation: Microbial Mechanisms and some Alternatives to Methyl Bromide

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The experiments reported here are part of a larger project supported by the California Strawberry Commission and ARS-USDA to research chemical and nonchemical alternatives to methyl bromide for preplant fumigation of soil in strawberry production. Chemical alternatives to methyl bromide have been tested in replicated field experiments at the Monterey Bay Academy near Watsonville, CA. Strawberry was grown every year, *Verticillium dahliae* was present in the soil, and bed fumigation treatments were applied in early October of each year. Two-row beds were shaped, fumigated (two shanks/bed, 15-20 cm deep, rates given per unit of treated bed area, which is 58% of the total area), and covered with black plastic mulch. Selva was transplanted through the plastic mulch one month later. Conventional practices for annual strawberry production and pest management for the area were followed, including sprinkler irrigation initially and drip irrigation in the production season. Berries were picked for fresh market at least weekly for several months by normal grower practice.

All of the bed fumigation treatments used in 4 years of experiments increased yield significantly in comparison to nonfumigated soil. For example, yields in 1997 and 1998, respectively, relative to those obtained following standard bed fumigation with methyl bromide/chloropicrin (67/33% @ 325 lb/acre), were 117 and 76% for chloropicrin alone (300 lb/acre), 105 and 87% for Telone/chloropicrin (65/35% @ 425 lb/acre), or 66 and 45% for nontreated soil. Application of the Telone/chloropicrin mixture to beds at the same rate in a water emulsion through drip lines gave yields of 102 and 104% relative to those obtained on beds fumigated with methyl bromide/chloropicrin, while broadcast fumigation with methyl bromide/chloropicrin (67/33%, 315-330 lb/acre total area) gave relative yields of 112 and 96%. All fumigation treatments reduced *V. dahliae* populations in soil and effectively controlled weed growth through plant holes in the plastic mulch. The results show that bed fumigations with the materials used can be effective and that drip application of emulsified Telone/chloropicrin shows promise, but the specific methods of application need further research. The use of a virtually impermeable black plastic mulch (Bromotec Y681B, Lawson Mardon Packaging, U.K.) in 1998 improved yields on average by 16% over those obtained with a standard black polyethylene mulch in the bed fumigation treatments above, and with chloropicrin or Telone/chloropicrin applied at rates reduced by one third.

Four experiments on a broccoli-strawberry rotation on nonfumigated soils have been completed. At Davis, CA, where *V. dahliae* is absent, one year of fallow or one year of broccoli production did not increase subsequent strawberry yields over those obtained with continuous strawberry production. Fumigation with methyl bromide/chloropicrin in the same experiment increased strawberry yields 54-69%. At the Watsonville site with high populations of *V. dahliae* present, a one-year rotation with broccoli increased subsequent strawberry yields by 24-38% and one year of rye increased yield 18-44%, relative to continuous strawberry, all on nonfumigated soil. Yield increases following one-year rotations out of strawberry, however, were approximately half as large as those obtained by soil fumigation in the same site and years. Although current California strawberry varieties are all susceptible to Verticillium wilt, the relationship of disease incidence to initial populations of *V. dahliae* in soil differed significantly between the varieties Selva and Camarosa.

We are researching microbiological differences associated with the enhanced growth and productivity of strawberries in soils fumigated with methyl bromide/chloropicrin where the response is not due to control of known, major pathogens. Plants in fumigated soils consistently had higher root length densities and fewer dark roots than plants in nonfumigated soils. Relative to nonfumigated soils, total numbers of fungi are usually low for several months following fumigation. *Cylindrocarpon* spp. were isolated from 0.5-cm segments of strawberry roots grown in nonfumigated soils (mean frequency 14%) but not from roots grown in fumigated soils. *Pythium* spp. were more commonly isolated from roots in nonfumigated soils, with mean isolation frequencies of 3 and 11% for fumigated and nonfumigated soils, respectively. *Rhizoctonia* spp. were frequently isolated from roots in both fumigated and nonfumigated soils. Pathogenicity of the predominant isolates of these fungi was tested on strawberry in the greenhouse. *Cylindrocarpon* spp. did not cause significant root rot, but some isolates caused significant reductions in shoot and root growth. *P. ultimum* caused root rot and growth reductions. Of the 14 binucleate isolates of *Rhizoctonia* spp. tested, four caused significant root rot and growth reductions, while three others caused only growth reductions. Total populations of bacteria in soil were not affected by fumigation, but fluorescent pseudomonads were significantly less 5 days after fumigation. Populations of fluorescent pseudomonads in soil, however, increased quickly following fumigation and were 10-1000 fold higher than in nonfumigated soils 10 days to 9 months after fumigation. Predominant isolates of fluorescent pseudomonads from the rhizosphere were tested for effects on strawberry growth in natural field soil in the greenhouse. The effects of individual isolates ranged from beneficial (increased shoot and root dry weights up to 72% and 162%, respectively) to deleterious (about 20% shoot or root reduction). *Pseudomonas fluorescens, P. putida* and *P. chlororaphis* were among the most predominant and beneficial rhizobacteria tested. The results suggest that reductions in deleterious fungi and increases in beneficial fluorescent pseudomonads contribute to the enhanced growth response of strawberry to soil fumigation with methyl bromide/chloropicrin.

Research currently in progress during the 1998-99 growing season includes the following:

1. Continued experiments on the microbial mechanisms by which strawberry growth and yield respond to soil fumigation, with further testing of potentially beneficial microorganisms.
2. A comparison of broadcast and bed fumigations, and further bed fumigation experiments on chloropicrin with and without Telone added. In cooperation with Husein Ajwa and Tom Trout, ARS-USDA, this includes the use of fumigants at relatively low rates, applied by shank injection or through drip lines as emulsions, and a comparison of standard polyethylene to a high-barrier plastic mulch.
3. Experiments on the possible use of ozone as a soil fumigant, both with and without the addition of beneficial microorganisms.
4. Experiments funded by the Statewide UC IPM Program on cultural management of Verticillium wilt in strawberry production, including crop rotations, organic soil amendments, determinations of inoculum thresholds for disease and yield losses, and development of improved methods to screen strawberry varieties for genetic tolerance or resistance to Verticillium wilt.

# A comparison of the weed control in strawberries resulting from bed fumigation with chloropicrin, Telone and methyl bromide.

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**Summary**

There is a general concern that the alternatives to methyl bromide are less efficacious on weeds than methyl bromide. The objective of this evaluation was to measure the weed control resulting from fumigation with chloropicrin, Telone and methyl bromide. At D&B Specialty Farms, Santa Maria, CA. treatments applied through the subsurface drip irrigation were chloropicrin EC at 14 and 24 GPA. Telone C35 EC at 21 and 35 GPA. Shank injection treatments were methyl bromide/chloropicrin at 300 lbs. per acre. An untreated check was also included. Each treatment was tarped with three types of plastic: black, clear virtually impermeable film, and clear standard tarp. Transplanting was completed on November 6, 1998 and the initial weed density counts, No. per 400 in$^2$, were made on November 11, 1998. Mean separation was performed using Fisher's protected LSD. Virtually impermeable film (VIF) improved the activity of Telone C35 EC at 21 GPA on filaree (Table 1). Over all fumigants the VIF improved the activity of all fumigants on filaree (Table 2). No fumigant or tarp effects on clover populations were detected.

**Table 1.** ANOVA by individual treatment.

| | Weed density (no. 400 in.$^2$) | | | |
|---|---|---|---|---|
| | Clover | | Filaree | |
| Treatment | Clear std. | VIF | Clear std. | VIF |
| 1. Chloropicrin 24 GPA | 2.7 ab | 3.5 ab | 1.0 abc | 1.3 ab |
| 2. Chloropicrin 14 GPA | 2.0 ab | 2.2 ab | 1.3 ab | 0.3 bc |
| 3. Telone C35 35 GPA | 5.7 a | 1.0 ab | 1.0 abc | 0.0 c |
| 4. Telone C35 21 GPA | 4.2 ab | 2.5 ab | 1.5 a | 0.2 c |
| 5. Nonfumigated | -- | -- | -- | -- |
| 6. M. bromide 300 lb/A | 4.5 ab | 0.2 b | 0.3 bc | 0.2 c |
| LSD 0.05 | 5.01 | | 1.05 | |

**Table 2.** Factorial analysis: main effect of tarp type.

| | Weed density (no. 400 in.$^2$) | |
|---|---|---|
| Tarp type | Clover | Filaree |
| Standard tarp | 3.8 | 1.0 a |
| VIF | 1.9 | 0.4 b |
| LSD 0.05 | 2.47 | 0.47 |

# Summary of Recent Research on Verticillium wilt in High Elevation Strawberry Nurseries


| | | |
|---|---|---|
| T.R. Gordon | K.D. Larson | D.V. Shaw |
| Plant Pathology | Pomology Department | Pomology Department |
| U.C. Davis | U.C. Davis | U.C. Davis |


During 1998, research continued on the use of chemical fumigants and cover crops for control of Verticillium wilt, caused by *Verticillium dahliae*, in high elevation strawberry nurseries. Six treatments were tested in a field experiment, which was initiated in 1995; each treatment had three replications, for a total of 18 plots. In one of these treatments, plots were kept fallow, while the other five treatments all had fall crops of rye in 1995 and 1996. Treatment two included spring plantings of mustard (canola), in 1996 and 1997, following incorporation of the fall rye crop. The mustard crops were cut and incorporated in the summer, and tarped for approximately one month. Treatments three through five had two years in rye followed by a chemical fumigation in August of 1997: either methyl bromide:chloropicrin (2:1) @ 350 pounds/acre, chloropicrin alone @ 250 pounds/acre, or C-35 (35% chloropicrin and 65% telone) @ 380 pounds/acre. The last treatment had two years in rye and no fumigation.

In April of 1998, all plots were planted to two strawberry cultivars, Camarosa and Selva. All fumigation treatments appeared to be equally effective in reducing soil populations of *V. dahliae*, which were undetectable (< 1 microsclerotium/gram of soil) in all the fumigated plots. Of the non-fumigated treatments, fallow had the lowest levels of *V. dahliae* (11 microsclerotia/gram), whereas the rye only and the rye/mustard treatments both had an average of 20 microsclerotia/gram. No disease was detectable in any of the fumigated plots. For Camarosa, 52, 56, and 76% of the plants had symptoms of Verticillium wilt in the rye, fallow, and rye/mustard treatments, respectively. For Selva, in both the rye and rye/mustard treatments, 87% of the plants were symptomatic, whereas 73% of the plants in fallowed plots had disease symptoms.

In summary, all the chemical fumigants provided adequate control of Verticillium wilt; whereas none of the non-chemical treatments was satisfactory. It should also be noted that fumigation experiments in previous years have shown less complete control with non-methyl bromide treatments. Thus chloropicrin alone or combined with telone may prove to be less consistent than the standard methyl bromide:chloropicrin combination.

In terms of runner production in the nursery, methyl bromide: chloropicrin was the best treatment. For Selva, plots receiving this treatment produced an average of 1331 runners per plot. The C-35 treatment (1117 runners/plot) was not significantly different from methyl bromide:chlorpicrin but chloropicrin alone was significantly worse (920 runners/plot). Similar results were obtained for Camarosa, although in this case, the differences between the fumigants were not statistically significant. Overall, the results indicate that the fumigants differ somewhat due to factors other than Verticillium. That is, although Verticillium wilt was not a problem in any of the fumigated plots, there were differences in productivity. This may reflect the activity of microorganisms in the soil that were differentially affected by the fumigants.

Runners representative of each nursery treatment have been planted at the South Coast field station (Camarosa) and at Watsonville (Selva) in order to evaluate any carry-over effects of the nursery treatments. Previous findings suggest that plants from nursery plots fumigated with chloropicrin or C-35 will not perform as well as those from methyl bromide:chloropicrin fumigated ground.

During 1999 we will also be evaluating the effects of post-harvest chilling treatments on plants from a high elevation nursery. Results from last year indicated that extended chilling periods significantly reduced the survival of *Verticillium dahliae* in infected runner plants. For example, in Selva stored at 34 F for 32 days, the pathogen was virtually eliminated. As a result, based on the cumulative fruit yield, there was no difference between plants from fumigated nursery plots and those from the same plots, which were inoculated prior to planting (at the nursery). However, fruit production by plants from non-fumigated plots never reached the levels of the plants from fumigated nursery plots, even with maximum chilling. This indicates that carry-over effects resulting from factors other than Verticillium are not negated by exposure to low temperatures.

Comparable effects were not been observed for Camarosa, where chilling was correlated with only a modest reduction in the incidence of Verticillium. However, because Camarosa is typically planted soon after harvest, the longest chilling period we tested was 17 days. Currently we are looking at the effects of longer chilling periods in Camarosa, to determine if this explains the difference between the two varieties. Preliminary indications are that Verticillium levels remain high, even when Camarosa is stored for >30 days. Thus, varietal differences may be important as well. We are also testing the effects of a late nursery harvest of Camarosa, to coincide with Selva, to determine if this contributes to a difference in the effects of post-harvest chilling. To gain further insight into the influence of variety on the chilling response, we have included Diamante in our current year's experiment, to provide a day neutral variety for comparison with Selva.

# Pomology Progress Report, South Coast Field Day 1999: Cultivar Improvement

Douglas V. Shaw and Kirk D. Larson, Department of Pomology, U.C. Davis

**U.C. Strawberry Breeding Program Overview.** The northern and southern California breeding programs have diverged in recent years due to the distinct varietal needs of the south coast and central coast production regions. As the two breeding programs have diverged, activities in both locations have increased. In 1998 over 10,000 seedlings were grown and evaluated at each location and over 500 new selections were entered into first stage of advanced testing. Program divergence has mandated two high- elevation nursery programs, with over 100 accession/harvest date combinations in 1998.

**Cultivars released in 1997.** There appears to be general acceptance of most of the recent UC releases. Extrapolation from estimated nursery acreage suggests that about 2,000 acres of Diamante, Aromas, and Gaviota will be in production in 1999, and that this acreage was limited by plant supply. The strengths and weaknesses of each cultivar on commercial scales appear about as expected from small plot research. Botrytis and color problems with Diamante were greater in 1998 than in the past, but only on the coast, and likely due in part to excessive wet conditions; good yields and excellent fruit quality were obtained inland. Due to its productivity and color, interest in Aromas is greater on the coast where Diamante problems were most obvious. A 4-year summary suggested that Camarosa outyields Gaviota in Watsonville, at least on a per-plant basis. Gaviota would need more plants per acre to be directly competitive; a decrease from 16" to 14" at 52" centers would suffice. Gaviota performed better in Santa Maria, out-yielding Camarosa substantially in 1998, due largely to its rain tolerance.

**Advanced selections.** Several of the 1994 selections from the Watsonville program have shown promise in two years of testing. The most advanced and the most exciting items are short day types intended as replacements for Camarosa from Santa Maria and north. Specific objectives are a plant that can be planted later and maintains a more compact plant form, has later initiation of production to avoid spring rain, suffers fewer disease problems, and has a lower cull rate to enhance harvest efficiency. Item 94.3-11 is very promising; it out-yielded Camarosa over two years with a smaller plant and lower cull rate. Item 94.3-10 has exceptional flavor, but may have too low yield to be directly competitive with Camarosa. Item 94.19-5 has exceptionally large fruit and a compact plant. No releases are expected in 1999, the earliest point at which a final decision on these items would be made is September 2000.

Promising selections from the South Coast program include a high-yielding item (94.256-607) with Verticillium wilt tolerance that is in a grower trial in Santa Maria, and more than one dozen 1996 selections that are in grower tests throughout the state. For southern California, breeding objectives include adaptation to early nursery digging, early fruit production, sustained yields throughout the winter and spring, a low cull rate, and environmental tolerance.

**Resistance Breeding.** Considerable effort has been invested in the development of superior germplasm with resistance/tolerance to Verticillium wilt and two-spotted mites. A collaborative project with Drs. Doug Gubler and Tom Gordon has established testing for Verticillium wilt resistance as a standard procedure in the evaluation of parental stock and advanced selections. Similarly, collaborative work with Dr. Frank Zalom has resulted in extensive information regarding germplasm tolerance/susceptibility to two-spotted mite injury. Most recently, collaborative work with Dr. Greg Browne was initiated with the intent to develop similar resistance evaluation efforts for Phytophthora root/crown rot.

# Pomology Progress Report, South Coast Field Day 1999: Cultural Practices

Kirk D. Larson and Douglas V. Shaw, Department of Pomology. U.C. Davis

**Chemical control of soil pathogens: Ridomil/Aliette trial results.** Severe *P. cactorum* induced plant collapse in the Diamante cultivar two years ago stimulated our interest in cultural methods of control. Metalaxyl (Ridomil) and various phosphorus acid products have been used in strawberry for years to mitigate these problems, although dispute is common over their effectiveness. Greenhouse experiments suggest little or no effectiveness of these compounds whereas growers and many nursery producers remain convinced. One possible explanation is that little effectiveness is realized when very severe infection of local soil is the issue. Conversely, with sufficient fumigation, most infection may be due to nursery origin rather than field infection. Preliminary results demonstrated substantial effectiveness of Alliette in decreasing plant collapse and increasing the yield of surviving plants, where the source of infection was nursery stock. Ridomil proved effective in reducing plant collapse, but also reduced the productivity of surviving plants. This previously unrecognized complementary activity in preventing collapse offset by stunting may explain the failure of past field experiments to demonstrate the effectiveness of Ridomil. Additional trials with these materials are planned.

**Root Pruning Trials.** Problems in establishing bare-root transplants are sometimes the result of improper planting: crowns planted too deep may suffer from root or crown rot. while crowns planted too high suffer from poor rooting, and poor growth and yield. A trial conducted last year demonstrated that there was no effect of root pruning on plant growth or yield, and that root pruning facilitated proper planting of transplants. Additional trials are in progress this year.

**1999 Fumigation Update.** Although domestic regulation provides for continued use of methyl bromide (MB) until 2005, alternatives research remain our project's top priority.

Variation in reported results due to statistical sampling and differences in the technical quality of research have generated a bewildering array of speculations about the effectiveness of MB and other materials. One way to mitigate these difficulties is to compile research summaries. The study set below contains over 45 studies conducted from 1987 to the present representing up to 7 major locations. What we know from this summary can be summarized as follows.

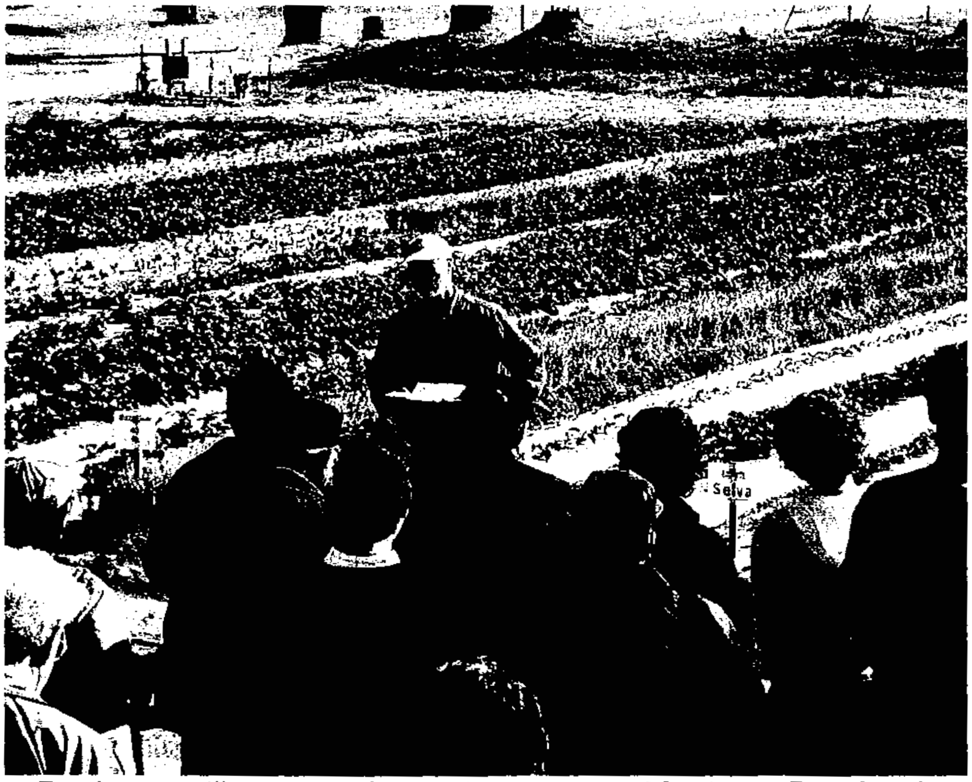
Without fumigation, yields drop an average of 37% in the first non-fumigated cycle, even in the absence of major pathogens. The yield drops further with each propagation cycle, perhaps leveling off at 50- 60%. In the 4th crop at Watsonville without fumigation (10 years since last fumigation, 1 fumigated crop, 3 NF crops and 5 cover crops intervening), the weeds are so bad that black plastic and herbicide application will be required hence forth. Fertilization and chilling treatments have been relatively ineffective in mitigating losses, major pathogens make things worse. These results do not include the negative aspects of using plants from non-fumigated nurseries, which exacerbates the lethal and non-specific soil pathogen problems.

Any fumigation alternative is better than none, but none are as effective as our current practice. Chloropicrin works reasonably well at high rates initially, but weakens on serial use. Growers are not likely to be permitted use of chloropicrin at the higher rates tested and moderate rates are considerably less effective, suffering rather serious yield losses and increased risk of lethal pathogen infestation. Telone-chloropicrin combinations work about as well as would be predicted from the rate of chloropicrin included, perhaps with some slight advantage over chloropicrin alone for control of lethal pathogens. A 300' buffer and a serious quantity use restriction will limit the utility of this compound as an alternative. Metam sodium has never worked well alone, some say it is inconsistent, our experience is that it is consistently substandard.

Our greatest success over the past 6 years has been with serial applications of chloropicrin and metam sodium. Results are substandard compared with current practices, this is definitely an expensive alternative, and technically more complicated. Technical drawbacks have also been observed due to planting through the tarp with day-neutral types. However, combined application is especially advantageous when only low rates of chloropicrin are permitted. This alternative also permits weed control sufficient to use clear polyethylene.

Our project also has conducted research to address the loss of methyl bromide in strawberry nurseries, and assure the continued quality or "fitness" of strawberry runner transplants. To this end, collaborative research with Dr. Tom Gordon resulted in the implementation and conclusion of a 3-year nursery crop rotation/soil fumigation trial. Results from this trial provided a 6th year of nursery productivity data for various MB alternatives, and demonstrated the ineffectiveness of crop rotation as a replacement for MB soil fumigation. Perhaps most importantly, Pomology nursery fumigation research has demonstrated that the loss of MB will impact strawberry nursery productivity, and that there is a significant "carry over" of nursery treatments into the fruiting field. Nursery fumigation research will continue in 1999 with a high-elevation nursery fumigation trial that was established this past fall.

Photos - Watsonville Strawberry Research Field Day - May 4, 1999




John Duniway outlines experimental program at Monterey Bay Academy.

Hussein Ajwa describes reduced-risk application using drip irrigation method.

# Appendix C

## Technical Handouts from 1998-9 Methyl Bromide Alternatives Tours

### Dates

**24 - 27 January 1999**
**22 - 24 April 1999**
**17 June 1999***
**20 - 22 July 1999**

* The 17 June 1999 tour was carried out for Paul Helliker and Doug Okumura, both of CDPR. These individuals visited the Watsonville area to observe field trials both on-farm and at the Monterey Bay Academy.

# 1998-1999 Strawberry Methyl Bromide Alternatives Tour

# January 24-27, 1999

**California Strawberry Commission**

## Schedule for the January 24-27 1999 MeBr Alternatives Trial Tour

**Sunday 24 January 1999**
Arrive in Watsonville area

**Monday 25 January 1999**
Watsonville/Santa Maria area tour

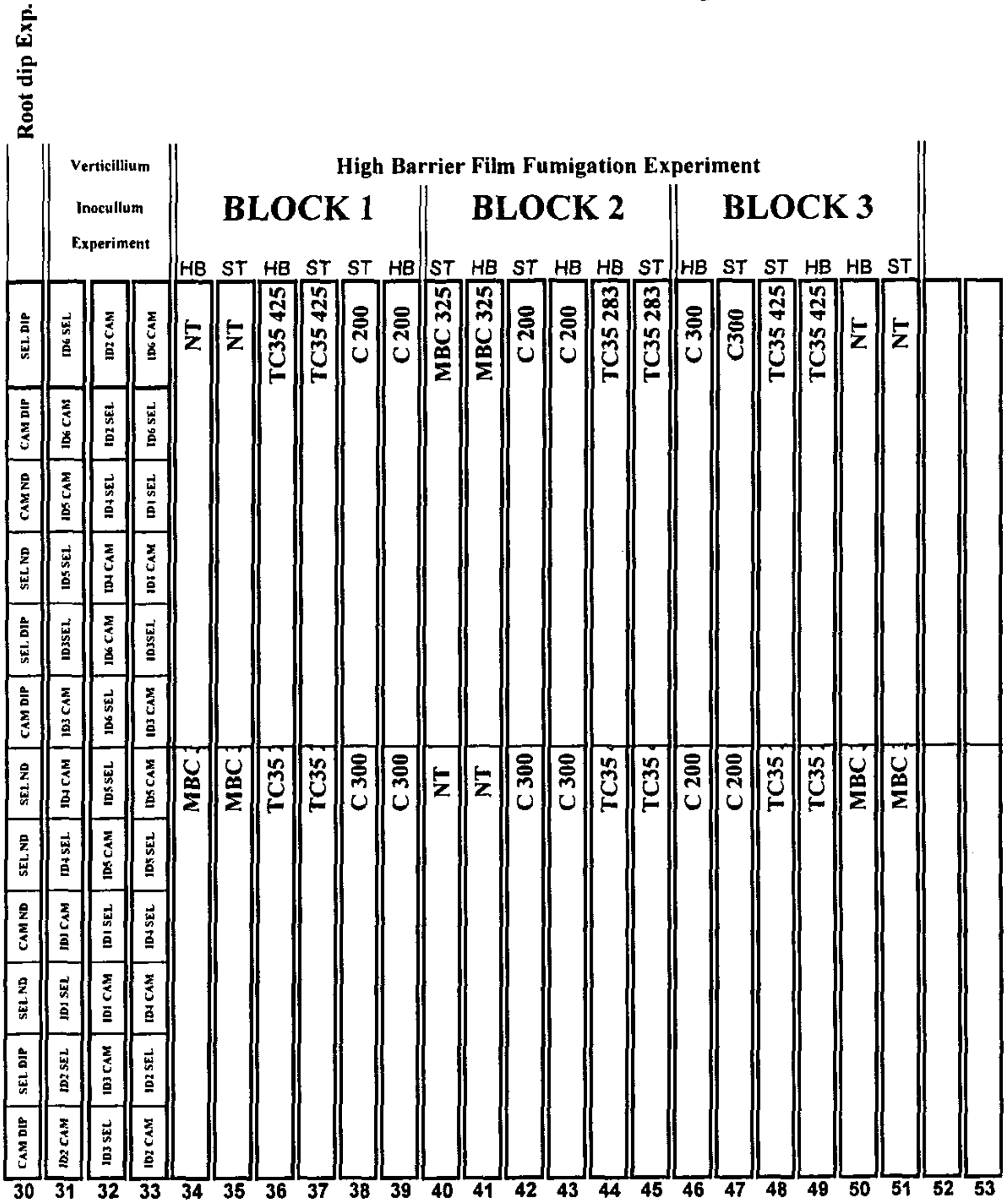
**Tuesday 26 January 1999**
Santa Maria/Oxnard area tour

**Wednesday 27 January 1999**
Irvine area tour

# 1998-99 Monterey Bay Academy

| Bed # | Treatment | |
|---|---|---|
| 1 | Multiple Varieties Partially Fumigated | |
| 2 | MeBr/Pic Flat Fumigated Selva 1-1 | Fumigated soil |
| 3 | Multiple Varieties Partially Fumigated | |
| 4 | | |
| 5 | | |
| 6 | Selva Not Fumigated 0-1 | |
| 7 | Camarosa Residue Incorporated | Rotation Block 1 |
| 8 | Rye/Brussels sprouts | Rotation Block 1 |
| 9 | Broccoli | Rotation Block 1 |
| 10 | Camarosa Residue Removed | Rotation Block 1 |
| 11 | Multiple Varieties Partially Fumigated | |
| 12 | MeBr/Pic Flat Fumigated Selva 1-2 | |
| 13 | Multiple Varieties Partially Fumigated | |
| 14 | Broccoli | Rotation Block 2 |
| 15 | Rye/Brussels sprouts | Rotation Block 2 |
| 16 | Camarosa Residue Incorporated/Removed | Rotation Block 2 |
| 17 | Selva Not Fumigated 0-2 | |
| 18 | | |
| 19 | | |
| 20 | Camarosa Residue Removed | Rotation Block 3 |
| 21 | Rye/Brussels sprouts | Rotation Block 3 |
| 22 | Broccoli | Rotation Block 3 |
| 23 | *Camarosa Residue Incorporated* | Rotation Block 3 |
| 24 | Selva Not Fumigated 0-3 | |
| 25 | | |
| 26 | | |
| 27 | Multiple Varieties Partially Fumigated | |
| 28 | MeBr/Pic Flat Fumigated Selva 1-3 | |
| 29 | Multiple Varieties Partially Fumigated | |

# MBA Beds 30 to 53 as used in 1998-1999 Experimental Cycle




Verticillium inoculum treatments
ID1=0 MS/gm soil (fumigated control)
ID2=0.5 MS/gm soil
ID3=2 MS/g soil
*ID4=5 MS/g soil*
ID5=10MS/g soil
ID6=30MS/g soil

bed 30 no fumigation
beds 31-33 bed fumigation with MBC 325
*beds 34-52 fumigated as indicated*
beds 52-53 non fumigated borders

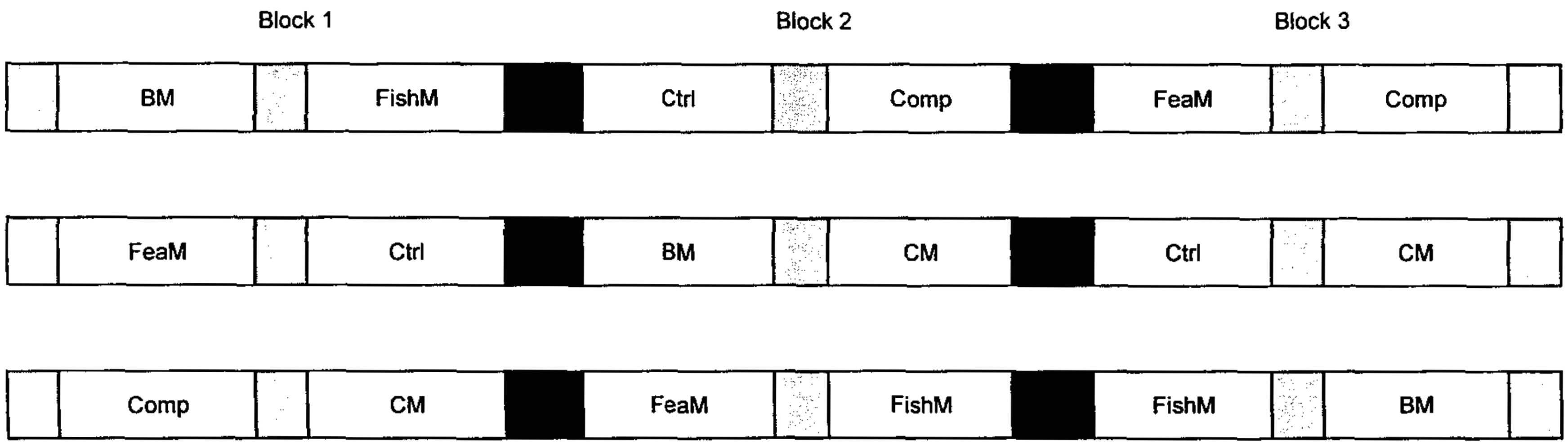
hb=high barrier film
st=standard film

# 1998-99 MBA -- Ozone Experiment

| Block 1 | | | Block 2 | | | Block 3 | | |
|---|---|---|---|---|---|---|---|---|
| $O_3$ | Control | $O_3$ & Tri | $O_3$ | $O_3$ & $CO_2$ | Tri | $O_3$ & Tri | $O_3$ & $O_2$ | Control |
| $O_3$ & $O_2$ | Tri | $O_3$ & $CO_2$ | Control | $O_3$ & Tri | $O_3$ & $O_2$ | Tri | $O_3$ | $O_3$ & $CO_2$ |

# Field plots for soil organic amendments experiment at MBA in 98-99

N




Treatments:
1. BM: Blood Meal @ 1% (w/w)
2. FishM: Fish Meal @ 1% (w/w)
3. FeaM: Feather Meal @ 1% (w/w)
4. CM: Chicken Manure @ 1% (w/w)
5. Comp: Compost @ 10 T/acre
6. Ctrl: Control (no amendment)

Plot size:
Each experiment unit=30'
3' gaps between units and 4' gaps between blocks

# Evaluation of Drip Irrigation Systems to Deliver Alternative Fumigants to Methyl Bromide for Strawberry Production

Husein Ajwa and Tom Trout, USDA-ARS
Water Management Research Laboratory, Fresno, CA

**Objectives:** to determine the distribution and efficacy of Telone C35 EC, Vapam, and Chloropicrin applied through drip irrigation systems, and to develop optimum irrigation parameters for strawberry production under the alternative fumigants.

Variables that are being evaluated include fumigants application rate, amount of water used to apply the fumigants, and application of combinations of fumigants.

## FUMIGANT APPLICATION TREATMENTS

| Trt# | Treatment Description |
|---|---|
| 1 | Untreated control |
| 2 | MeBr/Chloropicrin bed shank injection @ 425 lb/ac (245 lb/ac-bed) |
| 3 | Telone/Chloropicrin (Telone C35) bed shank injection @ 425 lb/ac |
| 4 | Telone C35 EC drip applied @ 425 lb/ac in 15 mm net irrigation |
| 5 | Telone C35 EC drip applied @ 425 lb/ac in 25 mm net irrigation |
| 6 | Telone C35 EC drip applied @ 425 lb/ac in 35 mm net irrigation |
| 7 | Telone C35 EC drip applied @ 255 lb/ac in 25 mm net irrigation |
| 8 | Vapam (42%) drip applied @ 75 gal/ac in 25 mm net irrigation |
| 9 | Vapam (42%) drip applied @ 75 gal/ac in 35 mm net irrigation |
| 10 | Vapam (40%) drip applied @ 50 gal/ac in 25 mm net irrigation |
| 11 | Telone C35 EC @ 255 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 12 | Chloropicrin @ 160 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 13 | Chloropicrin ~ 160 lb/a~ drip applied in 25 mm net irrigation |

## IRRIGATION TREATMENTS

Strawberry yield in Telone C35 bed shank injection (at 425 lb/ac and 255 lb/ac) will be irrigated by three irrigation amounts [75% (Low), 100% (Med.), and 125% (High) of crop evapotranspiration].

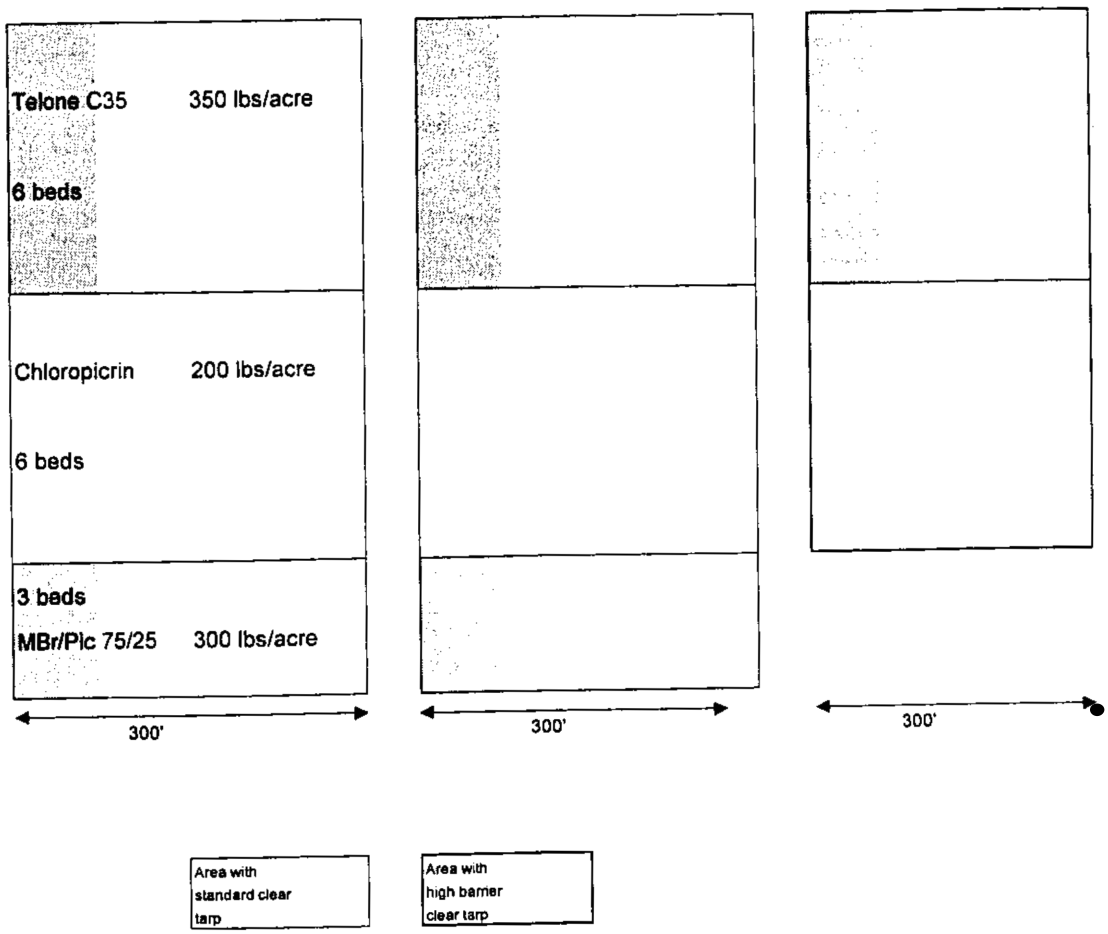
K A 1998-99

| | | | MBA 98 plots (Fumigated Sept 6-8, 1998) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Irrig | | | | | | | |
| # | | | | | (T13)-PicMw (25 mm) | (T9)-MvHw (35 mm) | (T5)-HtMw (25 mm) | (T12)-(Pic+Mv)Mw |
| 1 | M | Low Telone C35 Shank | High Telone C35 Shank | | (T7)-MtMw (25 mm) | (T8)-HvMw (25 mm) | (T10)-MvMw (25 mm) | (T2)-MeBr/Pic Shank |
| 2 | L | Low Telone C35 Shank | High Telone C35 Shank | | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) | (T13)-PicMw (25 mm) | (T6)-HtHw (35 mm) |
| 3 | H | Low Telone C35 Shank | High Telone C35 Shank | | (T4)-HtLw (15 mm) | (T12)-(Pic+Mv)Mw | (T8)-HvMw (25 mm) | (T9)-MvHw (35 mm) |
| 4 | H | High Telone C35 Shank | Low Telone C35 Shank | | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank | (T5)-HtMw (25 mm) |
| 5 | M | High Telone C35 Shank | Low Telone C35 Shank | | (T11)-(Mt+Mv)Mw | (T1)-Untreated control | (T12)-(Pic+Mv)Mw | (T4)-HtLw (15 mm) |
| 6 | L | High Telone C35 Shank | Low Telone C35 Shank | | (T9)-MvHw (35 mm) | (T3)-Telone/Pic Shank | (T1)-Untreated control | (T11)-(Mt+Mv)Mw |
| 7 | M | Low Telone C35 Shank | High Telone C35 Shank | | (T1)-Untreated control | (T4)-HtLw (15 mm) | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) |
| 8 | H | Low Telone C35 Shank | High Telone C35 Shank | | (T5)-HtMw (25 mm) | (T13)-PicMw (25 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank |
| 9 | L | Low Telone C35 Shank | High Telone C35 Shank | | (T12)-(Pic+Mv)Mw | (T2)-MeBr/Pic Shank | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) |
| 10 | M | High Telone C35 Shank | Low Telone C35 Shank | | (T10)-MvMw (25 mm) | (T11)-(Mt+Mv)Mw | (T9)-MvHw (35 mm) | (T8)-HvMw (25 mm) |
| 11 | L | High Telone C35 Shank | Low Telone C35 Shank | | (T3)-Telone/Pic Shank | (T6)-HtHw (35 mm) | (T11)-(Mt+Mv)Mw | (T1)-Untreated control |
| 12 | H | High Telone C35 Shank | Low Telone C35 Shank | | (T8)-HvMw (25 mm) | (T5)-HtMw (25 mm) | (T4)-HtLw (15 mm) | (T13)-PicMw (25 mm) |
| | | 35 ft | 35 ft | | 31 ft | 31 ft | 31 ft | 31 ft |

**1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials**

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Santa Maria, California



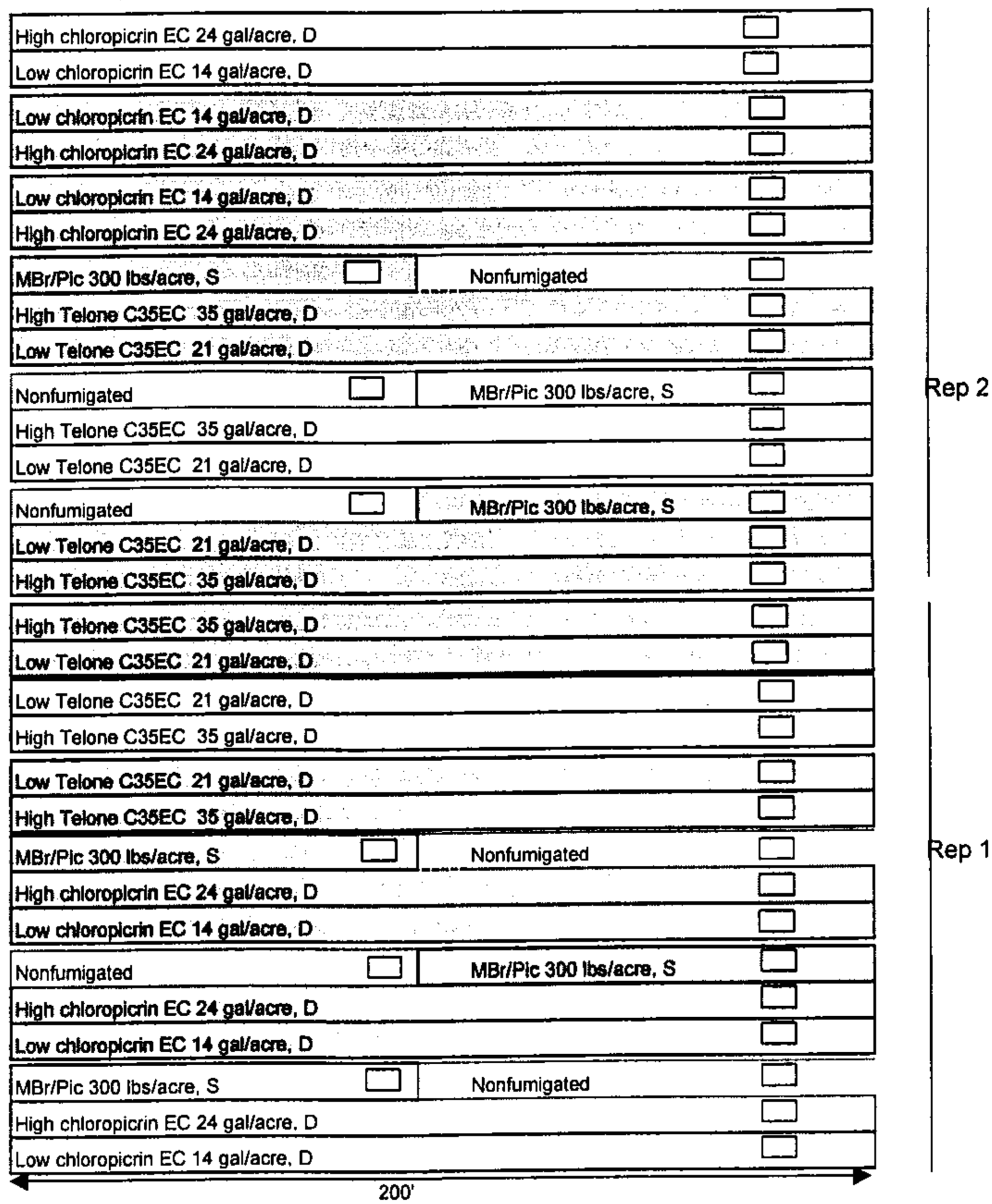
## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**

California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Santa Maria, California

| Fumigants | Tarps |
|---|---|
| 1 High chloropicrin EC 24 gal/acre, D | |
| 2 Low chloropicrin EC 14 gal/acre, D | Clear standard tarp |
| 3 High Telone C35EC 35 gal/acre, D | Clear virtually impermeable film tarp |
| 4 Low Telone C35EC 21 gal/acre, D | Black standard tarp |
| 5 Nonfumigated | D = Drip applied |
| 6 MBr/Pic 300 lbs/acre, S | S = Shank applied |



# A comparison of the weed control in strawberries resulting from bed fumigation with chloropicrin, Telone and methyl bromide.

Steve Fennimore, Extension Specialist
University of California, Davis

**Summary**
There is a general concern that the alternatives to methyl bromide are less efficacious on weeds than methyl bromide. The objective of this evaluation was to measure the weed control resulting from fumigation with chloropicrin, Telone and methyl bromide. At a farm in Santa Maria, CA, treatments applied through the subsurface drip irrigation were chloropicrin EC at 14 and 24 GPA, Telone C35 EC at 21 and 35 GPA. Shank injection treatments were methyl bromide/chloropicrin at 300 lbs. per acre. An untreated check was also included. Each treatment was tarped with three types of plastic: black, clear virtually impermeable film, and clear standard tarp. Transplanting was completed on November 6, 1998 and the initial weed density counts, No. per 400 in$^2$, were made on November 11, 1998. Mean separation was performed using Fisher's protected LSD. Virtually impermeable film (VIF) improved the activity of Telone C35 EC at 21 GPA on filaree (Table 1). Over all fumigants the VIF improved the activity of all fumigants on filaree (Table 2). No fumigant or tarp effects on clover populations were detected.

**Table 1.** ANOVA by individual treatment.

| | Weed density (no. 400 in.$^2$) | | | |
|---|---|---|---|---|
| | Clover | | Filaree | |
| Treatment | Clear std. | VIF | Clear std. | VIF |
| 1. Chloropicrin 24 GPA | 2.7 ab | 3.5 ab | 1.0 abc | 1.3 ab |
| 2. Chloropicrin 14 GPA | 2.0 ab | 2.2 ab | 1.3 ab | 0.3 bc |
| 3. Telone C35 35 GPA | 5.7 a | 1.0 ab | 1.0 abc | 0.0 c |
| 4. Telone C35 21 GPA | 4.2 ab | 2.5 ab | 1.5 a | 0.2 c |
| 5. Nonfumigated | -- | -- | -- | -- |
| 6. M. bromide 300 lb/A | 4.5 ab | 0.2 b | 0.3 bc | 0.2 c |
| LSD 0.05 | 5.01 | | 1.05 | |

**Table 2.** Factorial analysis: main effect of tarp type.

| | Weed density (no. 400 in.$^2$) | |
|---|---|---|
| Tarp type | Clover | Filaree |
| Standard tarp | 3.8 | 1.0 a |
| VIF | 1.9 | 0.4 b |
| LSD 0.05 | 2.47 | 0.47 |

**1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials**

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Oxnard, California - Site #2

400 feet | 400 feet

Rep #1 — ROAD

Block #1

| | | |
|---|---|---|
| 1 | Nonfumigated | 1 |
| 2 | MBr/Pic 75/25 - 330 #/a | 2 |
| 3 | Chloropicrin - low 120 #/a | 3 |
| 4 | Chloropicrin - high 200 #/a | 4 |
| 5 | Telone C35 - low 240 #/a | 5 |
| 6 | Telone C35 - high 350 #/a | 6 |
| 7 | Telone C35EC - low 21 gal/a | 7 |
| 8 | Telone C35EC - high 35 gal/a | 8 |
| 9 | Chloropicrin EC - low 12 gal/a | 9 |
| 10 | Chloropicrin EC - high 20 gal/a | 10 |

Block #2

| | | |
|---|---|---|
| 31 | Nonfumigated | 11 |
| 32 | MBr/Pic 75/25 - 330 #/a | 12 |
| 33 | Chloropicrin - low 120 #/a | 13 |
| 34 | Chloropicrin - high 200 #/a | 14 |
| 35 | Telone C35 - low 240 #/a | 15 |
| 36 | Telone C35 - high 350 #/a | 16 |
| 37 | Telone C35EC - low 21 gal/a | 17 |
| 38 | Telone C35EC - high 35 gal/a | 18 |
| 39 | Chloropicrin EC - low 12 gal/a | 19 |
| 40 | Chloropicrin EC - high 20 gal/a | 20 |

Rep #2 — ROAD

Block #3

| | | |
|---|---|---|
| 20 | Chloropicrin EC - high 20 gal/a | 11 |
| 18 | Telone C35EC - high 35 gal/a | 12 |
| 17 | Telone C35EC - low 21 gal/a | 13 |
| 19 | Chloropicrin EC - low 12 gal/a | 14 |
| 12 | MBr/Pic 75/25 - 330 #/a | 15 |
| 11 | Nonfumigated | 16 |
| 14 | Chloropicrin - high 200 #/a | 17 |
| 13 | Telone C35 - high 350 #/a | 18 |
| 16 | Chloropicrin - low 120 #/a | 19 |
| 15 | Telone C35 - low 240 #/a | 20 |

Block #4

| | | |
|---|---|---|
| 41 | Chloropicrin EC - high 20 gal/a | 10 |
| 42 | Telone C35EC - high 35 gal/a | 8 |
| 43 | Chloropicrin EC - low 12 gal/a | 9 |
| 44 | Telone C35EC - low 21 gal/a | 7 |
| 45 | Nonfumigated | 1 |
| 46 | MBr/Pic 75/25 - 330 #/a | 2 |
| 47 | Telone C35 - high 350 #/a | 6 |
| 48 | Chloropicrin - high 200 #/a | 4 |
| 49 | Chloropicrin - low 120 #/a | 3 |
| 50 | Telone C35 - low 240 #/a | 5 |

Rep #3 — ROAD

Block #5

| | | |
|---|---|---|
| 9 | Chloropicrin EC - low 12 gal/a | 21 |
| 7 | Telone C35EC - low 21 gal/a | 22 |
| 8 | Telone C35EC - high 35 gal/a | 23 |
| 10 | Chloropicrin EC - high 20 gal/a | 24 |
| 2 | MBr/Pic 75/25 - 330 #/a | 25 |
| 5 | Telone C35 - low 240 #/a | 26 |
| 4 | Chloropicrin - high 200 #/a | 27 |
| 1 | Nonfumigated | 28 |
| 3 | Chloropicrin - low 120 #/a | 29 |
| 6 | Telone C35 - high 350 #/a | 30 |

Block #6

| | | |
|---|---|---|
| 51 | Telone C35EC - high 35 gal/a | 18 |
| 52 | Chloropicrin EC - high 20 gal/a | 20 |
| 53 | Chloropicrin EC - low 12 gal/a | 19 |
| 54 | Telone C35EC - low 21 gal/a | 17 |
| 55 | Chloropicrin - low 120 #/a | 13 |
| 56 | Telone C35 - high 350 #/a | 16 |
| 57 | Telone C35 - low 240 #/a | 15 |
| 58 | Chloropicrin - high 200 #/a | 14 |
| 59 | MBr/Pic 75/25 - 330 #/a | 12 |
| 60 | Nonfumigated | 11 |

High barrier tarp

Standard tarp

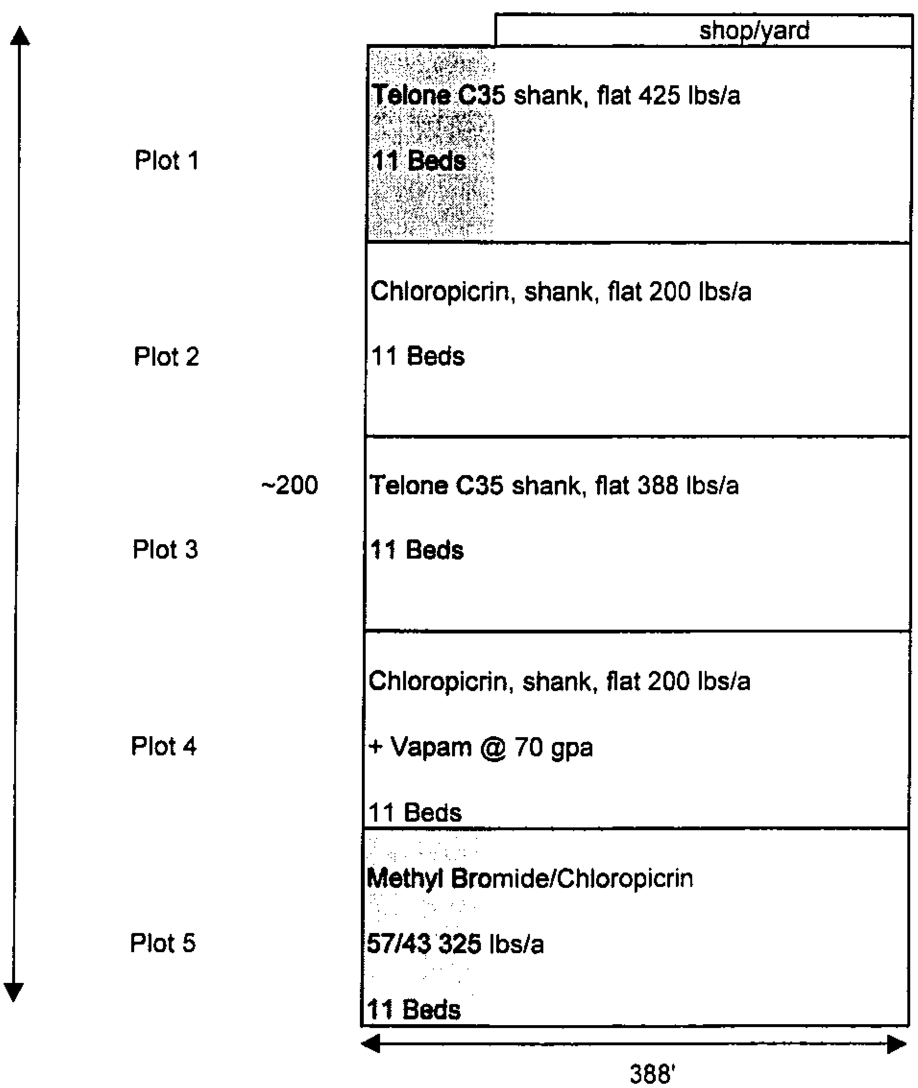
Drip applied treatment
or

## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**

California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

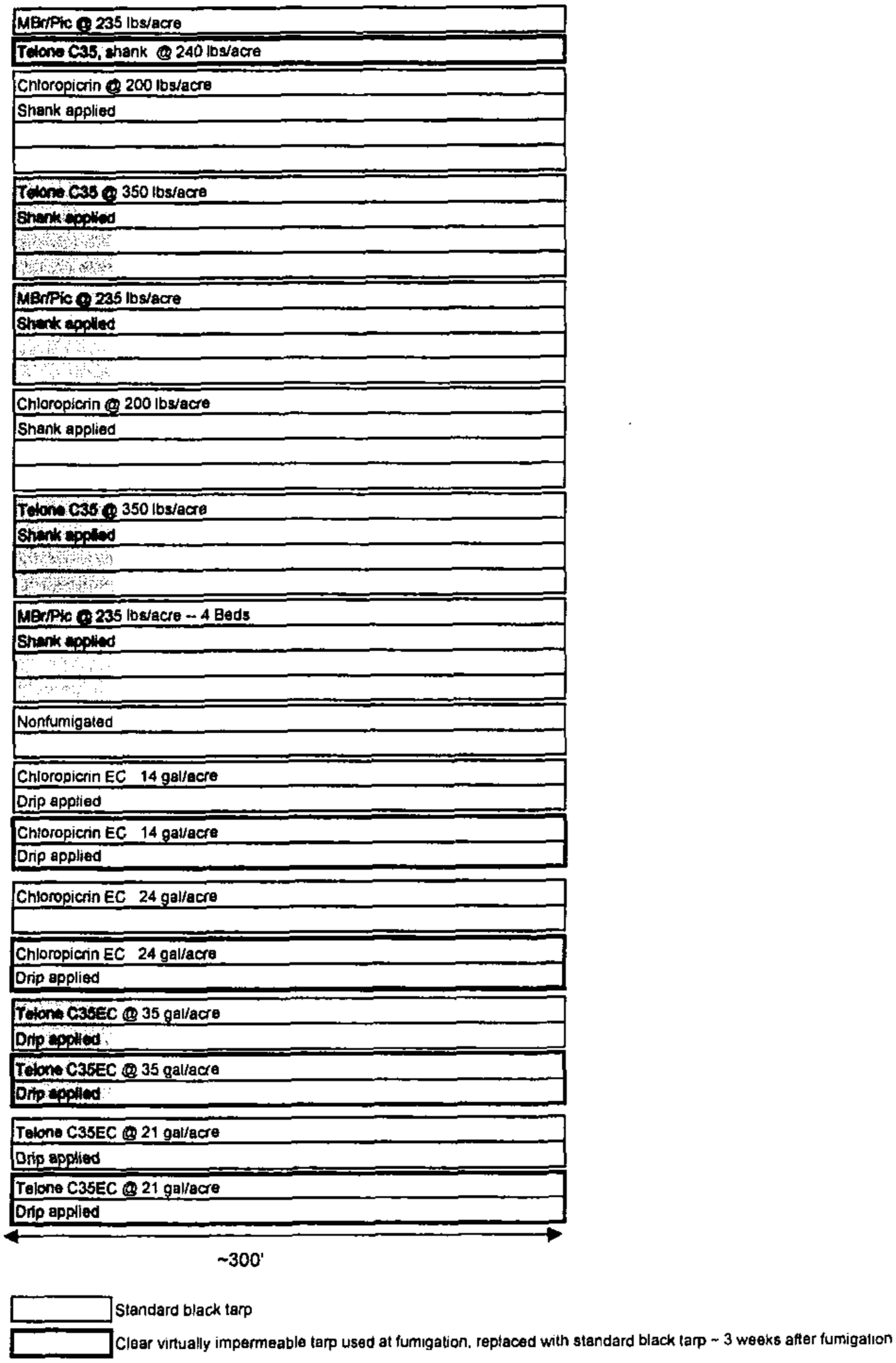
Trial location: Oxnard, California - Site #1



**1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials**

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Irvine, California



| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NF | NF | NF | ORG | ORG | ORG | C1 | C1 | C1 | MBC | MBC | MBC | C2 | C2 | C2 | C3 | C3 | C3 | ORG | ORG | ORG | NF | NF | NF |
| +cg | +cg | NF1 | NF2 | +cg | +cg | 3 | 5 | 2 | NF3 | BLK | CLR | 2 | 5 | 4 | 3 | 5 | 2 | | | | | | |
| -cg | -cg | NF2 | NF3 | -cg | -cg | 1 | 5 | 4 | NF2 | BLK | CLR | 3 | 5 | 1 | 1 | 5 | 4 | | | | | | |
| 3 | 5 | 1 | 4 | 5 | 3 | 1 | 5 | 4 | 2 | 5 | 4 | 3 | 5 | 2 | 1 | 5 | 3 | | | | | | |
| 4 | 5 | 2 | 1 | 5 | 2 | 2 | 5 | 3 | 3 | 5 | 1 | 4 | 5 | 1 | 2 | 5 | 4 | | | | | | |
| NF | NF | NF | ORG | ORG | ORG | CV1 | CV1 | CV1 | MBC | MBC | MBC | CV2 | CV2 | CV2 | CV3 | CV3 | CV3 | ORG | ORG | ORG | NF | NF | NF |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ORG | ORG | ORG | NF | NF | NF | CV2 | CV2 | CV2 | CV3 | CV3 | CV3 | CV1 | CV1 | CV1 | MBC | MBC | MBC | NF | NF | NF | ORG | ORG | ORG |
| +cg | +cg | NF3 | +cg | +cg | NF2 | 1 | 5 | 4 | 1 | 5 | 4 | 1 | 5 | 4 | NF2 | BLK | CLR | | | | | | |
| -cg | -cg | NF2 | -cg | -cg | NF3 | 3 | 5 | 2 | 3 | 5 | 2 | 2 | 5 | 3 | NF3 | BLK | CLR | | | | | | |
| 1 | 5 | 3 | 3 | 5 | 2 | 3 | 5 | 2 | 3 | 5 | 4 | 4 | 5 | 3 | 4 | 5 | 1 | | | | | | |
| 2 | 5 | 4 | 4 | 5 | 1 | 4 | 5 | 1 | 4 | 5 | 3 | 1 | 5 | 2 | 2 | 5 | 3 | | | | | | |
| ORG | ORG | ORG | NF | NF | NF | C2 | C2 | C2 | C3 | C3 | C3 | C1 | C1 | C1 | MBC | MBC | MBC | NF | NF | NF | ORG | ORG | ORG |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NF | NF | NF | ORG | ORG | ORG | C3 | C3 | C3 | C1 | C1 | C1 | MBC | MBC | MBC | C2 | C2 | C2 | NF | NF | NF | ORG | ORG | ORG |
| | | | | | | 4 | 5 | 2 | 2 | 5 | 3 | NF3 | BLK | CLR | 1 | 5 | 4 | NF2 | +cg | +cg | NF3 | +cg | +cg |
| | | | | | | 1 | 5 | 3 | 1 | 5 | 4 | NF2 | BLK | CLR | 2 | 5 | 3 | NF3 | -cg | -cg | NF2 | -cg | -cg |
| | | | | | | 1 | 5 | 2 | 2 | 5 | 4 | 2 | 5 | 3 | 3 | 5 | 4 | 1 | 5 | 4 | 2 | 5 | 3 |
| | | | | | | 3 | 5 | 4 | 3 | 5 | 1 | 4 | 5 | 1 | 1 | 5 | 2 | 3 | 5 | 2 | 1 | 5 | 4 |
| NF | NF | NF | ORG | ORG | ORG | CV3 | CV3 | CV3 | CV1 | CV1 | CV1 | MBC | MBC | MBC | CV2 | CV2 | CV2 | NF | NF | NF | ORG | ORG | ORG |

**Nursery trts**

1 = MBCP
2 = CP200
3 = Telone/C35
4 = NF (Rye rotation)
5 = Field Run
NF2 = NF (Brassica rotation)
NF3 = NF(Fallow rotation)

**Field trts**

C1=Pic@100#/a
C2=Pic@150#/a
C3=Pic#200#/a
MBC=MbPic@275#/a
CGM=corn gluten meal

CV1=Pic@100#/a +Vapam@70gpa
CV2=Pic@150#/a +Vapam@70gpa
CV3=Pic@200#/a +Vapam@70gpa
NF=nonfume, "conventional"
ORG="organic"

**Plant Material**

Macdoel Camarosa
dug Oct 4, planted Oct 9-10

# 1998-1999 Strawberry Methyl Bromide Alternatives Tour

# April 22-24, 1999

**California Strawberry Commission**

## Schedule for the April 22-24 1999 MeBr Alternatives Trial Tour

**Thursday 22 April 1999** – Watsonville/Salinas

| | |
|---|---|
| 0700 hours | Collect tourees from Monterey hotel(s) |
| 0800 hours | Meet at the CSC offices. Watsonville: Meet at CSC offices, visit Watsonville strawberry farms to see MeBr alternatives trials., view Monterey Bay Academy small plot trials |
| 1100 hours | Depart for Salinas |
| 1300 hours | Salinas; view USDA-ARS MeBr alternative plots at Spence Road research farm trials |

**Friday 23 April 1999** – Santa Maria/Oxnard

| | |
|---|---|
| 0800 hours | View MeBr trials in Santa Maria |
| 1315 hours | View MeBr trials in Oxnard, Site #1 |
| 1445 hours | View MeBr trials in Oxnard, Site #2 |

**Saturday 24 April** - Irvine

| | |
|---|---|
| 0730 hours | Depart from Oxnard |
| 1000 hours | View MeBr trial in Orange County |
| 1100 hours | View Mebr small plot trials at the South Coast Research and Extension Center. |
| 1200 hours | Disband |

## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**

California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Watsonville, California - Site #2

| | | |
|---|---|---|
| **Telone C35 EC 35 gallons/acre** | **Standard GREEN tarp** | **Drip** |
| **Telone C35 EC 35 gallons/acre** | **Standard clear tarp** | **Drip** |
| Telone C35 EC 35 gallons/acre | High barrier clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre | Standard clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre | High barrier clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre | Standard GREEN tarp | Drip |
| **MBr/Pic 67/33** | **Standard GREEN tarp** | **Shank** |

◄ 215' ►

The below treatments are located on another section of the farm.

| | | |
|---|---|---|
| **Telone C35 350 lbs/acre** | **Standard GREEN tarp** | **Shank** |
| Cholorpicrin 200 lbs/acre | *Standard GREEN tarp* | Shank |

# Weeding data, 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials
# Trial location: Watsonville, California - Site #2

**Weeding data**

Minutes hand weeding 0.046 acres

| | Date | | | | Total[1] | | | |
|---|---|---|---|---|---|---|---|---|
| | 12/11/1999 | 1/5/1999 | 2/13/1999 | 3/7/1999 | Minutes | Hours | Cost ($) | $/acre |
| Telone C35 EC 35 gallons/acre, drip applied, green tarp | 20 | 5.5[2] | 5 | 6 | 31 | 0.5 | $3.36 | $73.01 |
| Cholorpicrin EC 24 gallons/acre, drip applied, green tarp | 30 | 5.5 | 5 | 6 | 46.5 | 0.8 | $5.04 | $109.51 |
| Cholorpicrin EC 24 gallons/acre, drip applied, VIF clear tarp | 90 | 15 | 49.5 | 23 | 177.5 | 3.0 | $19.23 | $418.03 |
| Telone C35 EC 35 gallons/acre, drip applied, VIF clear tarp | 170 | 15 | 10 | 24 | 219 | 3.7 | $23.73 | $515.76 |
| Cholorpicrin EC 24 gallons/acre, drip applied, standard clear tarp | 145 | 20 | 56 | 20 | 241 | 4.0 | $26.11 | $567.57 |
| Telone C35 EC 35 gallons/acre, drip applied, standard clear tarp | 165 | 50 | 20 | 47 | 282 | 4.7 | $30.55 | $664.13 |

1 This represents only a portion of the seasonal weeding costs.

2 This time essentially represents walking the length of the bed.

# Response of Strawberry to Some Chemical and Cultural Alternatives to Methyl Bromide Fumigation of Soil

J. M. Duniway, C. L. Xiao, and W. D. Gubler
Department of Plant Pathology, University of California, Davis CA 95616

The experiments reported here are part of a larger project supported by the California Strawberry Commission, the California Department of Pesticide Regulation Pest Management Alliance Grant, and ARS-USDA to research chemical and nonchemical alternatives to methyl bromide for preplant fumigation of soil in strawberry production. Chemical alternatives to methyl bromide have been tested in replicated field experiments at the Monterey Bay Academy near Watsonville, CA. Strawberry was grown every year, *Verticillium dahliae* was present in the soil, and bed fumigation treatments were applied in early October of each year. Two-row beds were shaped, fumigated (two shanks/bed, 15-20 cm deep, rates given per unit of treated bed area, which is 58% of the total area), and covered with black plastic mulch. Selva was transplanted through the plastic mulch one month later. Conventional practices for annual strawberry production and pest management for the area were followed, including sprinkler irrigation initially and drip irrigation in the production season. Berries were picked for fresh market at least weekly for several months by normal grower practice.

All of the bed fumigation treatments used in 4 years of experiments increased yield significantly in comparison to nonfumigated soil. For example, yields in 1997 and 1998, respectively, relative to those obtained following standard bed fumigation with methyl bromide/chloropicrin (67/33% @ 325 lb/acre), were 117 and 76% for chloropicrin alone (300 lb/acre), 105 and 87% for Telone/chloropicrin (65/35% @ 425 lb/acre), or 66 and 45% for nontreated soil. Application of the Telone/chloropicrin mixture to beds at the same rate in a water emulsion through drip lines gave yields of 102 and 104% relative to those obtained on beds fumigated with methyl bromide/chloropicrin, while broadcast fumigation with methyl bromide/chloropicrin (67/33%, 315-330 lb/acre total area) gave relative yields of 112 and 96%. All fumigation treatments reduced *V. dahliae* populations in soil and effectively controlled weed growth through plant holes in the plastic mulch. The results show that bed fumigations with the materials used can be effective and that drip application of emulsified Telone/chloropicrin shows promise, but the specific methods of application need further research. The use of a virtually impermeable black plastic mulch (Bromotec Y681B, Lawson Mardon Packaging, U.K.) in 1998 improved yields on average by 16% over those obtained with a standard black polyethylene mulch in the bed fumigation treatments above, and with chloropicrin or Telone/chloropicrin applied at rates reduced by one third.

Four experiments on a broccoli-strawberry rotation on nonfumigated soils have been completed. At Davis, CA, where *V. dahliae* is absent, one year of fallow or one year of broccoli production did not increase subsequent strawberry yields over those obtained with continuous strawberry production. Fumigation with methyl bromide/chloropicrin in the same experiment increased strawberry yields 54-69%. At the Watsonville site with high populations of *V. dahliae* present, a one-year rotation with broccoli increased subsequent strawberry yields by 24-38% and one year of rye increased yield 18-44%, relative to continuous strawberry, all on nonfumigated soil. Yield increases following one-year rotations out of strawberry, however, were approximately half as large as those obtained by soil fumigation in the same site and years. Although current California strawberry varieties are all susceptible to Verticillium wilt, the relationship of disease incidence to initial populations of *V. dahliae* in soil differed significantly between the varieties Selva and Camarosa.

We are researching microbiological differences associated with the enhanced growth and productivity of strawberries in soils fumigated with methyl bromide/chloropicrin where the response is not due to control of known, major pathogens. Plants in fumigated soils consistently had higher root length densities and fewer dark roots than plants in nonfumigated soils. Relative to nonfumigated soils, total numbers of fungi are usually low for several months following fumigation. *Cylindrocarpon* spp. were isolated from 0.5-cm segments of strawberry roots grown in nonfumigated soils (mean frequency 14%) but not from roots grown in fumigated soils. *Pythium* spp. were more commonly isolated from roots in nonfumigated soils, with mean isolation

frequencies of 3 and 11% for fumigated and nonfumigated soils, respectively. *Rhizoctonia* spp. were frequently isolated from roots in both fumigated and nonfumigated soils. Pathogenicity of the predominant isolates of these fungi was tested on strawberry in the greenhouse. *Cylindrocarpon* spp. did not cause significant root rot, but some isolates caused significant reductions in shoot and root growth. *P. ultimum* caused root rot and growth reductions. Of the 14 binucleate isolates of*Rhizoctonia* spp. tested, four caused significant root rot and growth reductions, while three others caused only growth reductions. Total populations of bacteria in soil were not affected by fumigation, but fluorescent pseudomonads were significantly less 5 days after fumigation. Populations of fluorescent pseudomonads in soil, however, increased quickly following fumigation and were 10-1000 fold higher than in nonfumigated soils 10 days to 9 months after fumigation. Predominant isolates of fluorescent pseudomonads from the rhizosphere were tested for effects on strawberry growth in natural field soil in the greenhouse. The effects of individual isolates ranged from beneficial (increased shoot and root dry weights up to 72% and 162%, respectively) to deleterious (about 20% shoot or root reduction). *Pseudomonas fluorescens*, *P. putida* and *P. chlororaphis* were among the most predominant and beneficial rhizobacteria tested. The results suggest that reductions in deleterious fungi and increases in beneficial fluorescent pseudomonads contribute to the enhanced growth response of strawberry to soil fumigation with methyl bromide/chloropicrin.

Research currently in progress during the 1998-99 growing season includes the following:

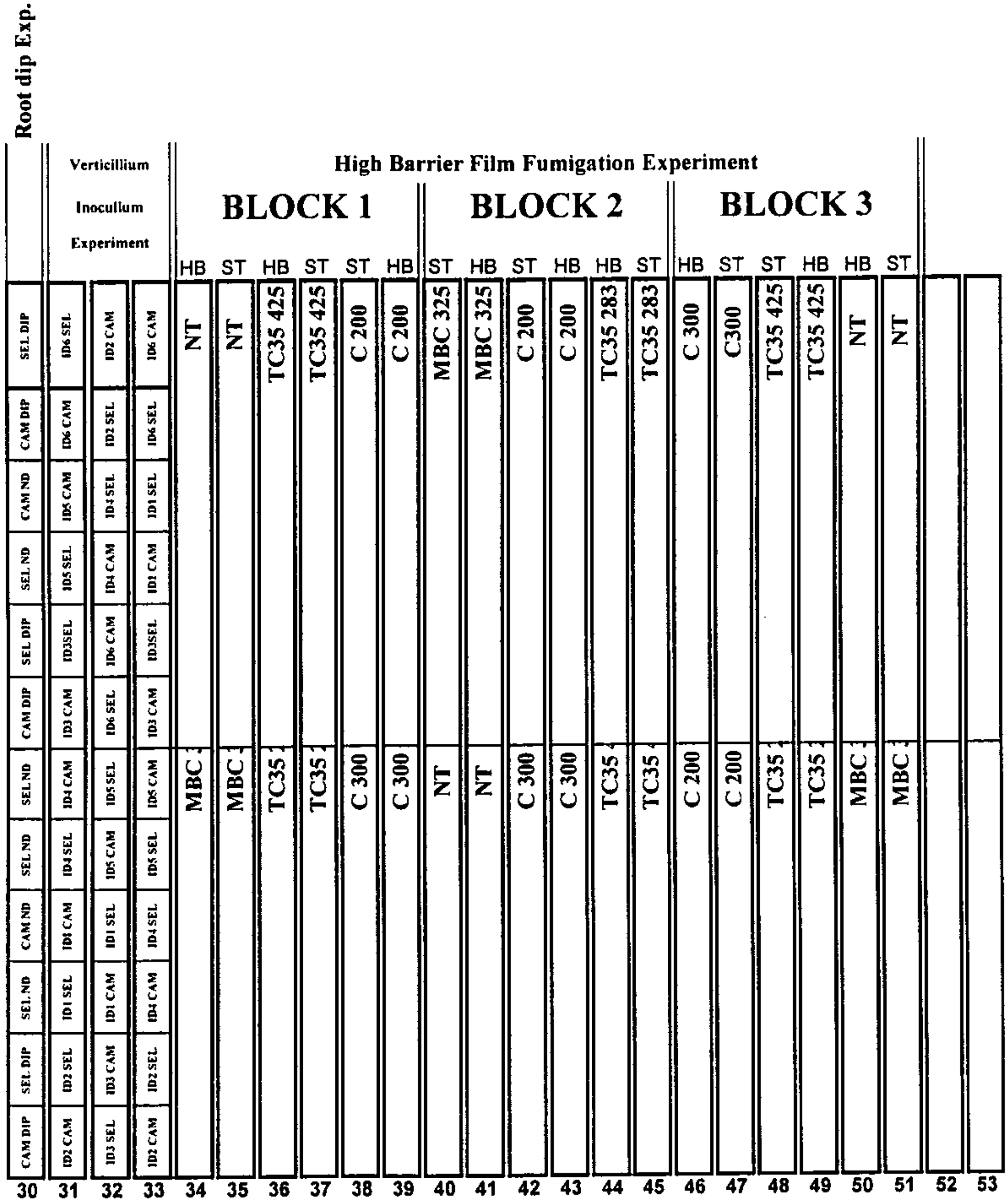
1. Continued experiments on the microbial mechanisms by which strawberry growth and yield respond to soil fumigation, with further testing of potentially beneficial microorganisms.
2. A comparison of broadcast and bed fumigations, and further bed fumigation experiments on chloropicrin with and without Telone added. In cooperation with Husein Ajwa and Tom Trout, ARS-USDA, this includes the use of fumigants at relatively low rates, applied by shank injection or through drip lines as emulsions, and a comparison of standard polyethylene to a high-barrier plastic mulch.
3. Experiments on the possible use of ozone as a soil fumigant, both with and without the addition of beneficial microorganisms.
4. Experiments funded by the California Department of Pesticide Regulation Pest Management Alliance Grant and Statewide UC IPM Program on cultural management of Verticillium wilt in strawberry production, including crop rotations, organic soil amendments, determinations of inoculum thresholds for disease and yield losses, and development of improved methods to screen strawberry varieties for genetic tolerance or resistance to Verticillium wilt.

# 1998-99 Monterey Bay Academy

Fumigated soil

| Bed # | | |
|---|---|---|
| 1 | Multiple Varieties Partially Fumigated | |
| 2 | MeBr/Pic Flat Fumigated Selva 1-1 | |
| 3 | Multiple Varieties Partially Fumigated | |
| 4 | | |
| 5 | | |
| 6 | *Selva Not Fumigated 0-1* | |
| 7 | Camarosa Residue Incorporated | Rotation Block 1 |
| 8 | Rye/Brussels sprouts | Rotation Block 1 |
| 9 | Broccoli | Rotation Block 1 |
| 10 | Camarosa Residue Removed | Rotation Block 1 |
| 11 | Multiple Varieties Partially Fumigated | |
| 12 | MeBr/Pic Flat Fumigated Selva [illegible] | |
| 13 | Multiple Varieties Partially Fumigated | |
| 14 | Broccoli | Rotation Block 2 |
| 15 | Rye/Brussels sprouts | Rotation Block 2 |
| 16 | Camarosa Residue Incorporated/Removed | Rotation Block 2 |
| 17 | Selva Not Fumigated 0-2 | |
| 18 | | |
| 19 | | |
| 20 | *Camarosa Residue Removed* | Rotation Block 3 |
| 21 | Rye/Brussels sprouts | Rotation Block 3 |
| 22 | Broccoli | Rotation Block 3 |
| 23 | Camarosa Residue Incorporated | Rotation Block 3 |
| 24 | Selva Not Fumigated 0-3 | |
| 25 | | |
| 26 | | |
| 27 | Multiple Varieties Partially Fumigated | |
| 28 | MeBr/Pic Flat Fumigated Selva [illegible] | |
| 29 | Multiple Varieties Partially Fumigated | |

# MBA Beds 30 to 53 as used in 1998-1999 Experimental Cycle




Verticillium inoculum treatments
ID1=0 MS/gm soil (fumigated control)
ID2=0.5 MS/gm soil
ID3=2 MS/g soil
ID4=5 MS/g soil
ID5=10MS/g soil
ID6=30MS/g soil

bed 30 no fumigation
beds 31-33 bed fumigation with MBC 325
beds 34-52 fumigated as indicated
beds 52-53 non fumigated borders

hb=high barrier film
st=standard film

# 1998-99 MBA -- Ozone Experiment

| Block 1 | | | Block 2 | | | Block 3 | | |
|---|---|---|---|---|---|---|---|---|
| $O_3$ | Control | $O_3$ & Tri | $O_3$ | $O_3$ & $CO_2$ | Tri | $O_3$ & Tri | $O_3$ & $O_2$ | Control |
| $O_3$ & $O_2$ | Tri | $O_3$ & $CO_2$ | Control | $O_3$ & Tri | $O_3$ & $O_2$ | Tri | $O_3$ | $O_3$ & $CO_2$ |

# Field plots for soil organic amendments experiment at MBA in 98-99

↑ N

| Block 1 | | Block 2 | | Block 3 | |
|---|---|---|---|---|---|
| BM | FishM | Ctrl | Comp | FeaM | Comp |
| FeaM | Ctrl | BM | CM | Ctrl | CM |
| Comp | CM | FeaM | FishM | FishM | BM |

Treatments:
1. BM: Blood Meal @ 1% (w/w)
2. FishM: Fish Meal @ 1% (w/w)
3. FeaM: Feather Meal @ 1% (w/w)
4. CM: Chicken Manure @ 1% (w/w)
5. Comp: Compost @ 10 T/acre
6. Ctrl: Control (no amendment)

Plot size:
Each experiment unit=30'
3' gaps between units and 4' gaps between blocks

# Evaluation of Drip Irrigation Systems to Deliver Alternative Fumigants to Methyl Bromide for Strawberry Production

Husein Ajwa and Tom Trout, USDA-ARS
Water Management Research Laboratory, Fresno, CA

**Objectives:** to determine the distribution and efficacy of Telone C35 EC, Vapam, and Chloropicrin applied through drip irrigation systems, and to develop optimum irrigation parameters for strawberry production under the alternative fumigants.

Variables that are being evaluated include fumigants application rate, amount of water used to apply the fumigants, and application of combinations of fumigants.

## FUMIGANT APPLICATION TREATMENTS

| Trt# | Treatment Description |
|---|---|
| 1 | Untreated control |
| 2 | MeBr/Chloropicrin bed shank injection @ 425 lb/ac (245 lb/ac-bed) |
| 3 | Telone/Chloropicrin (Telone C35) bed shank injection @ 425 lb/ac |
| 4 | Telone C35 EC drip applied @ 425 lb/ac in 15 mm net irrigation |
| 5 | Telone C35 EC drip applied @ 425 lb/ac in 25 mm net irrigation |
| 6 | Telone C35 EC drip applied @ 425 lb/ac in 35 mm net irrigation |
| 7 | Telone C35 EC drip applied @ 255 lb/ac in 25 mm net irrigation |
| 8 | Vapam (42%) drip applied @ 75 gal/ac in 25 mm net irrigation |
| 9 | Vapam (42%) drip applied @ 75 gal/ac in 35 mm net irrigation |
| 10 | Vapam (40%) drip applied @ 50 gal/ac in 25 mm net irrigation |
| 11 | Telone C35 EC @ 255 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 12 | Chloropicrin @ 160 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 13 | Chloropicrin ~ 160 lb/a~ drip applied in 25 mm net irrigation |

## IRRIGATION TREATMENTS

Strawberry yield in Telone C35 bed shank injection (at 425 lb/ac and 255 lb/ac) will be irrigated by three irrigation amounts [75% (Low), 100% (Med.), and 125% (High) of cropevapotranspiration].

MBA 1998-99

| # | Irrig | | | | | MBA 98 plots (Fumigated Sept 6-8, 1998) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | (T13)-PicMw (25 mm) | (T9)-MvHw (35 mm) | (T5)-HtMw (25 mm) | (T12)-(Pic+Mv)Mw |
| 1 | M | Low Telone C35 Shank | High Telone C35 Shank | | (T7)-MtMw (25 mm) | (T8)-HvMw (25 mm) | (T10)-MvMw (25 mm) | (T2)-MeBr/Pic Shank |
| 2 | L | Low Telone C35 Shank | High Telone C35 Shank | | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) | (T13)-PicMw (25 mm) | (T6)-HtHw (35 mm) |
| 3 | H | Low Telone C35 Shank | High Telone C35 Shank | | (T4)-HtLw (15 mm) | (T12)-(Pic+Mv)Mw | (T8)-HvMw (25 mm) | (T9)-MvHw (35 mm) |
| 4 | H | High Telone C35 Shank | Low Telone C35 Shank | | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank | (T5)-HtMw (25 mm) |
| 5 | M | High Telone C35 Shank | Low Telone C35 Shank | | (T11)-(Mt+Mv)Mw | (T1)-Untreated control | (T12)-(Pic+Mv)Mw | (T4)-HtLw (15 mm) |
| 6 | L | High Telone C35 Shank | Low Telone C35 Shank | | (T9)-MvHw (35 mm) | (T3)-Telone/Pic Shank | (T1)-Untreated control | (T11)-(Mt+Mv)Mw |
| 7 | M | Low Telone C35 Shank | High Telone C35 Shank | | (T1)-Untreated control | (T4)-HtLw (15 mm) | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) |
| 8 | H | Low Telone C35 Shank | High Telone C35 Shank | | (T5)-HtMw (25 mm) | (T13)-PicMw (25 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank |
| 9 | L | Low Telone C35 Shank | High Telone C35 Shank | | (T12)-(Pic+Mv)Mw | (T2)-MeBr/Pic Shank | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) |
| 10 | M | High Telone C35 Shank | Low Telone C35 Shank | | (T10)-MvMw (25 mm) | (T11)-(Mt+Mv)Mw | (T9)-MvHw (35 mm) | (T8)-HvMw (25 mm) |
| 11 | L | High Telone C35 Shank | Low Telone C35 Shank | | (T3)-Telone/Pic Shank | (T6)-HtHw (35 mm) | (T11)-(Mt+Mv)Mw | (T1)-Untreated control |
| 12 | H | High Telone C35 Shank | Low Telone C35 Shank | | (T8)-HvMw (25 mm) | (T5)-HtMw (25 mm) | (T4)-HtLw (15 mm) | (T13)-PicMw (25 mm) |
| | | 35 ft | 35 ft | | 31 ft | 31 ft | 31 ft | 31 ft |

## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Watsonville, California - Site #1

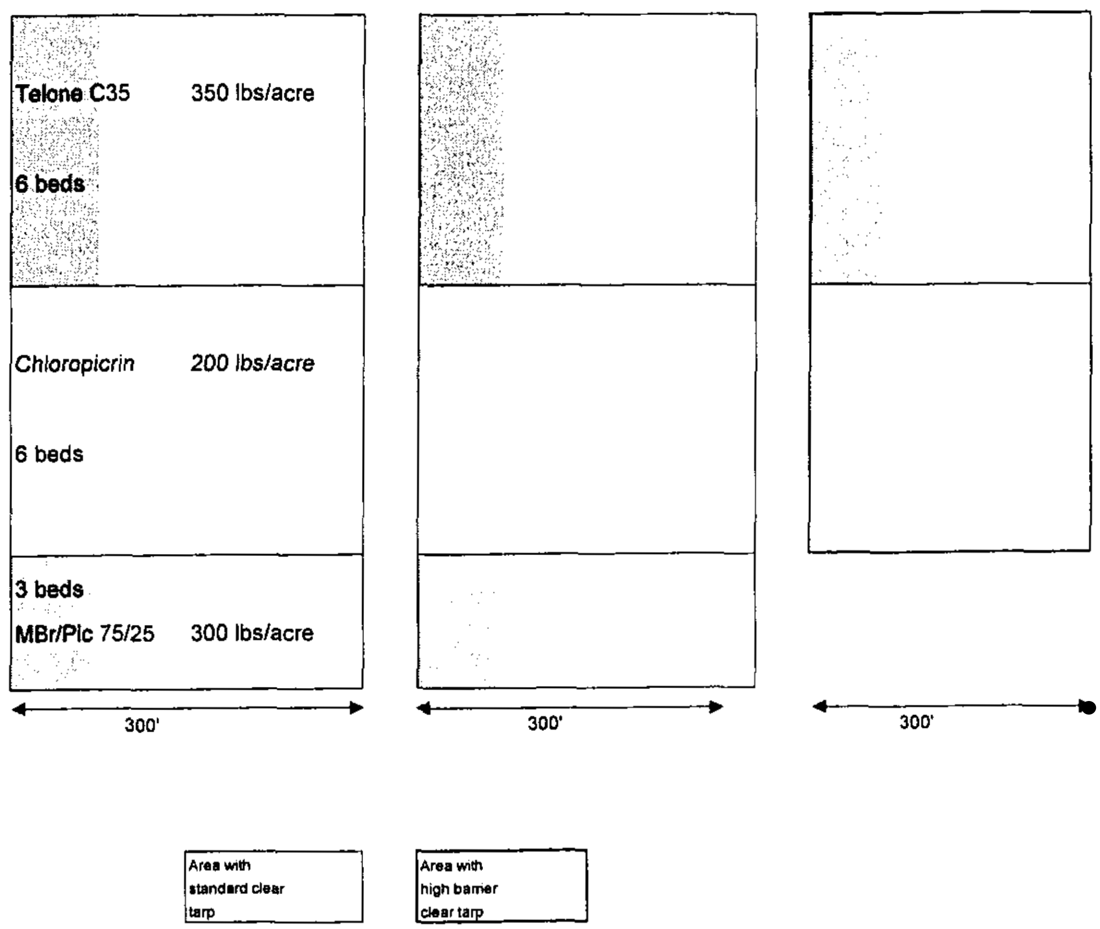
| | |
|---|---|
| Chloropicrin EC 24 gallons/acre<br>Standard tarp | Drip |
| Chloropicrin EC 24 gallons/acre<br>High barrier tarp | Drip |
| Telone C35 EC 35 gallons/acre<br>Standard tarp | Drip |
| Telone C35 EC 35 gallons/acre<br>High barrier tarp | Drip |
| Cholorpicrin 120 lbs acre<br>Standard tarp | Shank |
| Chloropicrin 200 lbs/acre<br>Standard tarp | Shank |
| Cholorpicrin 120 lbs acre<br>High barrier tarp | Shank |
| Chloropicrin 200 lbs/acre<br>High barrier tarp | Shank |
| Telone C35 210 lbs/acre<br>Standard tarp | Shank |
| Telone C35 350 lbs/acre<br>Standard tarp | Shank |
| Telone C35 210 lbs/acre<br>High barrier tarp | Shank |
| Telone C35 350 lbs/acre<br>High barrier tarp | Shank |
| MBr/Pic 67/33<br>Standard tarp | Shank |

250'

**1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials**

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

*Trial location:* *Santa Maria, California*



# 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

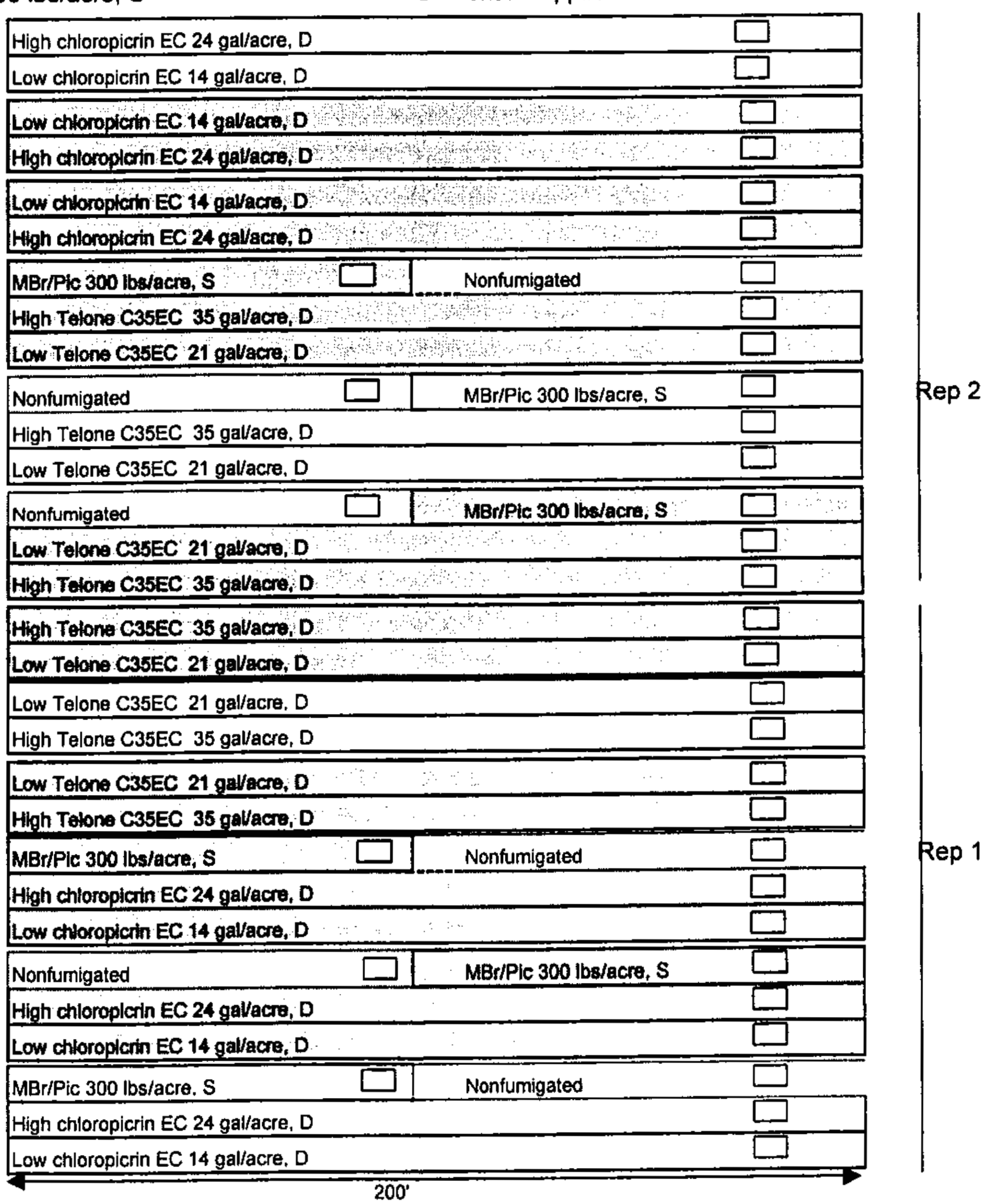
Trial location: Santa Maria, California

**Fumigants**

1 High chloropicrin EC 24 gal/acre, D
2 Low chloropicrin EC 14 gal/acre, D
3 High Telone C35EC 35 gal/acre, D
4 Low Telone C35EC 21 gal/acre, D
5 Nonfumigated
6 MBr/Pic 300 lbs/acre, S

**Tarps**

Clear standard tarp
Clear virtually impermeable film tarp
Black standard tarp
D = Drip applied
S = Shank applied



## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**

California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Oxnard, California - Site #2

400 feet | 400 feet

**Rep #1 — ROAD**

Block #1

| | | |
|---|---|---|
| 1 | Nonfumigated | 1 |
| 2 | MBr/Pic 75/25 - 330 #/a | 2 |
| 3 | Chloropicrin - low 120 #/a | 3 |
| 4 | Chloropicrin - high 200 #/a | 4 |
| 5 | Telone C35 - low 240 #/a | 5 |
| 6 | Telone C35 - high 350 #/a | 6 |
| 7 | Telone C35EC - low 21 gal/a | 7 |
| 8 | Telone C35EC - high 35 gal/a | 8 |
| 9 | Chloropicrin EC - low 12 gal/a | 9 |
| 10 | Chloropicrin EC - high 20 gal/a | 10 |

Block #2

| | | |
|---|---|---|
| 31 | Nonfumigated | 11 |
| 32 | MBr/Pic 75/25 - 330 #/a | 12 |
| 33 | Chloropicrin - low 120 #/a | 13 |
| 34 | Chloropicrin - high 200 #/a | 14 |
| 35 | Telone C35 - low 240 #/a | 15 |
| 36 | Telone C35 - high 350 #/a | 16 |
| 37 | Telone C35EC - low 21 gal/a | 17 |
| 38 | Telone C35EC - high 35 gal/a | 18 |
| 39 | Chloropicrin EC - low 12 gal/a | 19 |
| 40 | Chloropicrin EC - high 20 gal/a | 20 |

**Rep #2 — ROAD**

Block #3

| | | |
|---|---|---|
| 20 | Chloropicrin EC - high 20 gal/a | 11 |
| 18 | Telone C35EC - high 35 gal/a | 12 |
| 17 | Telone C35EC - low 21 gal/a | 13 |
| 19 | Chloropicrin EC - low 12 gal/a | 14 |
| 12 | MBr/Pic 75/25 - 330 #/a | 15 |
| 11 | Nonfumigated | 16 |
| 14 | Chloropicrin - high 200 #/a | 17 |
| 13 | Telone C35 - high 350 #/a | 18 |
| 16 | Chloropicrin - low 120 #/a | 19 |
| 15 | Telone C35 - low 240 #/a | 20 |

Block #4

| | | |
|---|---|---|
| 41 | Chloropicrin EC - high 20 gal/a | 10 |
| 42 | Telone C35EC - high 35 gal/a | 8 |
| 43 | Chloropicrin EC - low 12 gal/a | 9 |
| 44 | Telone C35EC - low 21 gal/a | 7 |
| 45 | Nonfumigated | 1 |
| 46 | MBr/Pic 75/25 - 330 #/a | 2 |
| 47 | Telone C35 - high 350 #/a | 6 |
| 48 | Chloropicrin - high 200 #/a | 4 |
| 49 | Chloropicrin - low 120 #/a | 3 |
| 50 | Telone C35 - low 240 #/a | 5 |

**Rep #3 — ROAD**

Block #5

| | | |
|---|---|---|
| 9 | Chloropicrin EC - low 12 gal/a | 21 |
| 7 | Telone C35EC - low 21 gal/a | 22 |
| 8 | Telone C35EC - high 35 gal/a | 23 |
| 10 | Chloropicrin EC - high 20 gal/a | 24 |
| 2 | MBr/Pic 75/25 - 330 #/a | 25 |
| 5 | Telone C35 - low 240 #/a | 26 |
| 4 | Chloropicrin - high 200 #/a | 27 |
| 1 | Nonfumigated | 28 |
| 3 | Chloropicrin - low 120 #/a | 29 |
| 6 | Telone C35 - high 350 #/a | 30 |

Block #6

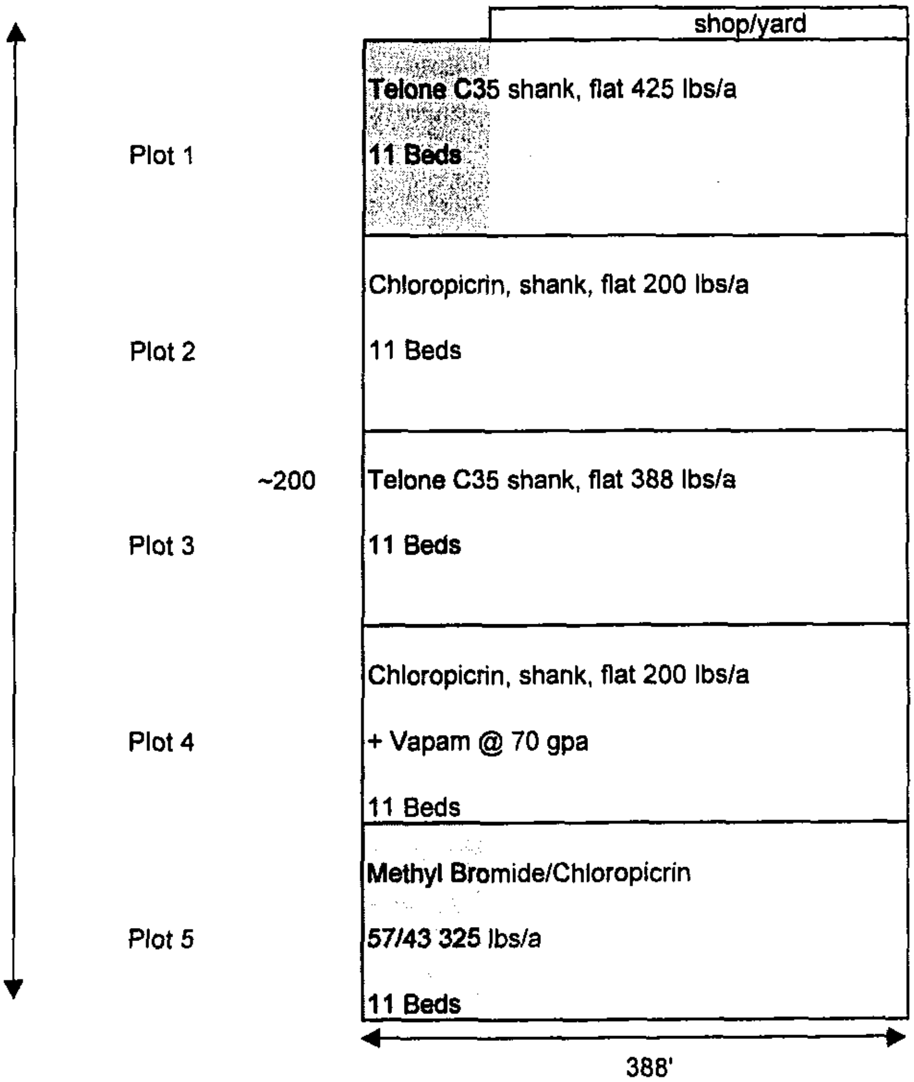
| | | |
|---|---|---|
| 51 | Telone C35EC - high 35 gal/a | 18 |
| 52 | Chloropicrin EC - high 20 gal/a | 20 |
| 53 | Chloropicrin EC - low 12 gal/a | 19 |
| 54 | Telone C35EC - low 21 gal/a | 17 |
| 55 | Chloropicrin - low 120 #/a | 13 |
| 56 | Telone C35 - high 350 #/a | 16 |
| 57 | Telone C35 - low 240 #/a | 15 |
| 58 | Chloropicrin - high 200 #/a | 14 |
| 59 | MBr/Pic 75/25 - 330 #/a | 12 |
| 60 | Nonfumigated | 11 |

High barrier tarp
Standard tarp
Drip applied treatment
or

## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Oxnard, California - Site #1



## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**

California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Irvine, California

| |
|---|
| MBr/Pic @ 235 lbs/acre |
| Telone C35, shank @ 240 lbs/acre |
| Chloropicrin @ 200 lbs/acre |
| Shank applied |
| |
| |
| Telone C35 @ 350 lbs/acre |
| Shank applied |
| |
| |
| MBr/Pic @ 235 lbs/acre |
| Shank applied |
| |
| |
| Chloropicrin @ 200 lbs/acre |
| Shank applied |
| |
| |
| Telone C35 @ 350 lbs/acre |
| Shank applied |
| |
| |
| MBr/Pic @ 235 lbs/acre -- 4 Beds |
| Shank applied |
| |
| |
| Nonfumigated |
| |
| Chloropicrin EC 14 gal/acre |
| Drip applied |
| Chloropicrin EC 14 gal/acre |
| Drip applied |
| Chloropicrin EC 24 gal/acre |
| |
| Chloropicrin EC 24 gal/acre |
| Drip applied |
| Telone C35EC @ 35 gal/acre |
| Drip applied |
| Telone C35EC @ 35 gal/acre |
| Drip applied |
| Telone C35EC @ 21 gal/acre |
| Drip applied |
| Telone C35EC @ 21 gal/acre |
| Drip applied |

~300'

Standard black tarp

Clear virtually impermeable tarp used at fumigation, replaced with standard black tarp ~ 3 weeks after fumigation

## 1998-1999 On Farm Strawberry Methyl Bromide MeBr Alternatives Trials, List of Treatments by Coastal Location

*Trials sponsored by CSC/USDA-ARS/CDPR PMA*

| Location | Fumigant | Application method | Standard tarp | Color | VIF Tarp | Color |
|---|---|---|---|---|---|---|
| Irvine | Methyl bromide/Chloropicrin | Bed fumigation, shank | x | Black | | |
| | Telone C35 | Bed fumigation, shank | x | Black | | |
| | Telone C35EC | Bed fumigation, drip | x | Black | x | *Clear, to be replaced with standard black tarp* |
| | Chloropicrin | Bed fumigation, shank | x | Black | | |
| | Chloropicrin EC | Bed fumigation, drip applied | x | Black | x | Clear, to be replaced with standard black tarp |
| Oxnard Site #1 | Methyl bromide/Chloropicrin | Flat fumigation, shank | x | Clear | | |
| | Telone C35 | Flat fumigation, shank | x | Clear | | |
| | Chloropicrin | Flat fumigation, shank | x | Clear | | |
| | Chloropicrin + Vapam | Flat fumigation, shank + drip, bed | x | Clear | | |
| Oxnard Sie #2 | Untreated | – | x | Clear | x | Clear |
| | Methyl bromide/Chloropicrin | Bed fumigation, shank | x | Clear | x | Clear |
| | Telone C35 | Bed fumigation, shank + drip | x | Clear | x | Clear |
| | Telone C35EC | Bed fumigation, shank + drip | x | Clear | x | Clear |
| | Chloropicrin | Bed fumigation, shank | x | Clear | x | Clear |
| | Chloropicrin EC | Bed fumigation, drip | x | Clear | x | Clear |
| Santa Maria | Untreated | – | x | Clear, black | x | Clear |
| | Methyl bromide/Chloropicrin | Bed fumigation, shank | x | Clear, black | x | Clear |
| | Telone C35 | Bed fumigation, shank | x | Clear, black | x | Clear |
| | Telone C35EC | Bed fumigation, drip | x | Clear, black | x | Clear |
| | Chloropicrin | Bed fumigation, shank | x | Clear, black | x | Clear |
| | Chloropicrin EC | Bed fumigation, drip | x | Clear, black | x | Clear |
| Watsonville Site #1 | Methyl bromide/Chloropicrin | Bed fumigation, shank | x | Clear | x | Clear |
| | Telone C35 | Bed fumigation, shank | x | Clear | x | Clear |
| | Telone C35EC | Bed fumigation, drip | x | Clear | x | Clear |
| | Chloropicrin | Bed fumigation, shank | x | Clear | x | Clear |
| | Chloropicrin EC | Bed fumigation, drip | x | Clear | x | Clear |
| Watsonville Site #2 | Methyl bromide/Chloropicrin | Bed fumigation, shank | x | Green | x | Clear |
| | Telone C35 | Bed fumigation, shank | x | Green | x | Clear |
| | Telone C35EC | Bed fumigation, drip | x | Clear, green | x | Clear |
| | Chloropicrin | Bed fumigation, shank | x | Green | x | Clear |
| | Chloropicrin EC | Bed fumigation, drip | x | Clear, green | x | Clear |
| Watsonville Site #3 | Methyl bromide/Chloropicrin | Flat and bed fumigation, shank | x | Black | x | Black |
| | Telone C35 | Bed fumigation, shank | x | Black | x | Black |
| | Telone C35EC | Bed fumigation, drip | x | Black | x | Black |
| | Chloropicrin | Bed fumigation, shank | x | Black | x | Black |
| | Chloropicrin EC | Bed fumigation, drip | x | Black | x | Black |
| | Vapam | Bed fumigation, drip | x | Black | | |
| | Telone C35EC + Vapam | Bed fumigation, drip | x | Black | | |
| | Chloropicrin EC + Vapam | Bed fumigation, drip | x | Black | | |
| | Crop rotation | Bed | x | Black | | |
| | Soil amendments | Bed | x | Black | | |

Photo 1. USDA-ARS scientist addresses tour attendees at the USDA-ARS Spence Road Field Station in Salinas, California during the April 1999 Methyl Bromide Alternatives Tour.

Photo 2. USDA-ARS scientist Frank Martin describes to attendees the program of tests at the Monterey Bay Academy (near Watsonville, California) during the April 1999 Methyl Bromide Alternatives tour.

Photo 3. USDA-ARS scientist Hussein Ajwa displays to attendees the results of tests using reduced-risk approaches to fumigation, at the Monterey Bay Academy (near Watsonville, California) during the April 1999 Methyl Bromide Alternatives tour.

Photo 4. Strawberry grower discusses his observations regarding reduced-risk applications made using drip irrigation systems, at the Monterey Bay Academy (near Watsonville, California) during the April, 1999 Methyl Bromide Alternatives tour.

Photo 5. Strawberry grower addressing Federal and State officials, other growers, and allied industry representatives at Watsonville Site #1 (California) during the April, 1999 Methyl Bromide Alternatives tour.

Photo 6. Strawberry grower addresses tour attendees at Watsonville Site #1 (California) during the April, 1999 Methyl Bromide Alternatives tour.

Photo 7. Strawberry grower addressing other growers, Federal and State officials, and miscellaneous attendees at Watsonville Site #2 (California) during the April, 1999 Methyl Bromide Alternatives tour.

Photo 8. Strawberry grower presenting his observations to other attendees at trials in Santa Maria, California during the April, 1999 Methyl Bromide Alternatives tour.

Photo 9. Strawberry grower discussing observations with other attendees at trials at Oxnard Site #1 (California) during the April, 1999 Methyl Bromide Alternatives tour.

Photo 10. Strawberry grower discussing observations with other attendees at trials at Oxnard Site #2 (California) during the April, 1999 Methyl Bromide Alternatives tour.

Photo 11. Strawberry growers discuss the outcome of trials in Irvine, California during the April, 1999 Methyl Bromide Alternatives tour.

Photo 12. Strawberry growers review experimental findings with scientists and other attendees at trials in Irvine, California during the April, 1999 Methyl Bromide Alternatives tour.

Photo 13. University of California scientist Kirk Larson discusses research into alternative soil fumigants, at the South Coast Research and Extension Center in Irvine, California, during the April, 1999 Methyl Bromide Alternatives tour.

# Strawberry Methyl Bromide Alternatives

# June 17, 1999

**California Strawberry Commission**

The strawberry industry in California could be characterized by innovation and explosive growth. In 1979 there were 11,500 acres devoted to strawberry production in California. Over the period 1979 to 1993 the strawberry acreage in California increased, on average, by 1,030 acres per year due to new areas coming into production, introduction of new varieties, improved cultural practices and better crop protection tools. Over the period 1994-1998 the California strawberry acreage has held steady at about 24,000 acres. The result of the tremendous industry growth has been an increase in the amount of strawberries on the market and a large decrease in per unit return to the farm gate, thus making any significant detrimental change in production practices a threat to the viability of the industry.

Strawberry farmers were early adopters of preplant soil fumigation with methyl bromide due to the virtual elimination of soil-borne pathogens (notably *Verticillium* spp., *Phytophthora* spp.) and other pests (nematodes, weeds, arthropods, etc.) for a growing season, thus allowing farmers and researchers alike to focus on other factors that limited production. Nearly 100% of the California strawberry (both fruit and nursery production) acreage is presently preplant fumigated with methyl bromide, and it is the fumigant of choice due to its efficacy across many different growing situations (soil types, temperatures, moisture, etc.).

Faced with the loss of methyl bromide the California Strawberry Commission initiated a comprehensive research program with the USDA-ARS, the University of California and allied industries to focus on projects designed to find economical methyl bromide alternatives for strawberry production. (In fact, the California strawberry industry has been supporting agricultural research, including soil fumigation, for over 50 years) The research approach taken thus far has been two-pronged. The first prong consists of small plot research designed to identify economically viable alternatives to methyl bromide, their efficacy and use parameters. The second prong is designed to evaluate the best methyl bromide alternatives in large plots (≥ 0.5 acres) on-farm under actual farming situations. Methyl bromide alternatives tested thus far include chloropicrin, Telone C35, Vapam and Basamid.

The following are handouts are on-farm methyl bromide alternative trials or handouts presented by researchers at California Strawberry Commission sponsored research fields days in 1999.

## Response of Strawberry to Soil Fumigation: Microbial Mechanisms and some Alternatives to Methyl Bromide

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The experiments reported here are part of a larger project supported by the California Strawberry Commission and ARS-USDA to research chemical and nonchemical alternatives to methyl bromide for preplant fumigation of soil in strawberry production. Chemical alternatives to methyl bromide have been tested in replicated field experiments at the Monterey Bay Academy near Watsonville, CA. Strawberry was grown every year, *Verticillium dahliae* was present in the soil, and bed fumigation treatments were applied in early October of each year. Two-row beds were shaped, fumigated (two shanks/bed, 15-20 cm deep, rates given per unit of treated bed area, which is 58% of the total area), and covered with black plastic mulch. Selva was transplanted through the plastic mulch one month later. Conventional practices for annual strawberry production and pest management for the area were followed, including sprinkler irrigation initially and drip irrigation in the production season. Berries were picked for fresh market at least weekly for several months by normal grower practice.

All of the bed fumigation treatments used in 4 years of experiments increased yield significantly in comparison to nonfumigated soil. For example, yields in 1997 and 1998, respectively, relative to those obtained following standard bed fumigation with methyl bromide/chloropicrin (67/33% @ 325 lb/acre), were 117 and 76% for chloropicrin alone (300 lb/acre), 105 and 87% for Telone/chloropicrin (65/35% @ 425 lb/acre), or 66 and 45% for nontreated soil. Application of the Telone/chloropicrin mixture to beds at the same rate in a water emulsion through drip lines gave yields of 102 and 104% relative to those obtained on beds fumigated with methyl bromide/chloropicrin, while broadcast fumigation with methyl bromide/chloropicrin (67/33%, 315-330 lb/acre total area) gave relative yields of 112 and 96%. All fumigation treatments reduced *V. dahliae* populations in soil and effectively controlled weed growth through plant holes in the plastic mulch. The results show that bed fumigations with the materials used can be effective and that drip application of emulsified Telone/chloropicrin shows promise, but the specific methods of application need further research. The use of a virtually impermeable black plastic mulch (Bromotec Y681B, Lawson Mardon Packaging, U.K.) in 1998 improved yields on average by 16% over those obtained with a standard black polyethylene mulch in the bed fumigation treatments above, and with chloropicrin or Telone/chloropicrin applied at rates reduced by one third.

Four experiments on a broccoli-strawberry rotation on nonfumigated soils have been completed. At Davis, CA, where *V. dahliae* is absent, one year of fallow or one year of broccoli production did not increase subsequent strawberry yields over those obtained with continuous strawberry production. Fumigation with methyl bromide/chloropicrin in the same experiment increased strawberry yields 54-69%. At the Watsonville site with high populations of *V. dahliae* present, a one-year rotation with broccoli increased subsequent strawberry yields by 24-38% and one year of rye increased yield 18-44%, relative to continuous strawberry, all on nonfumigated soil. Yield increases following one-year rotations out of strawberry, however, were approximately half as large as those obtained by soil fumigation in the same site and years. Although current California strawberry varieties are all susceptible to Verticillium wilt, the relationship of disease incidence to initial populations of *V. dahliae* in soil differed significantly between the varieties Selva and Camarosa.

We are researching microbiological differences associated with the enhanced growth and productivity of strawberries in soils fumigated with methyl bromide/chloropicrin where the response is not due to control of known, major pathogens. Plants in fumigated soils consistently had higher root length densities and fewer dark roots than plants in nonfumigated soils. Relative to nonfumigated soils, total numbers of fungi are usually low for several months following fumigation. *Cylindrocarpon* spp. were isolated from 0.5-cm segments of strawberry roots grown in nonfumigated soils (mean frequency 14%) but not from roots grown in fumigated soils. *Pythium* spp. were more commonly isolated from roots in nonfumigated soils, with mean isolation frequencies of 3 and 11% for fumigated and nonfumigated soils, respectively. *Rhizoctonia* spp. were frequently isolated from roots in both fumigated and nonfumigated soils. Pathogenicity of the predominant isolates of these fungi was tested on strawberry in the greenhouse. *Cylindrocarpon* spp. did not cause significant root rot, but some isolates caused significant reductions in shoot and root growth. *P. ultimum* caused root rot and growth reductions. Of the 14 binucleate isolates of *Rhizoctonia* spp. tested, four caused significant root rot and growth reductions, while three others caused only growth reductions. Total populations of bacteria in soil were not affected by fumigation, but fluorescent pseudomonads were significantly less 5 days after fumigation. Populations of fluorescent pseudomonads in soil, however, increased quickly following fumigation and were 10-1000 fold higher than in nonfumigated soils 10 days to 9 months after fumigation. Predominant isolates of fluorescent pseudomonads from the rhizosphere were tested for effects on strawberry growth in natural field soil in the greenhouse. The effects of individual isolates ranged from beneficial (increased shoot and root dry weights up to 72% and 162%, respectively) to deleterious (about 20% shoot or root reduction). *Pseudomonas fluorescens, P. putida* and *P. chlororaphis* were among the most predominant and beneficial rhizobacteria tested. The results suggest that reductions in deleterious fungi and increases in beneficial fluorescent pseudomonads contribute to the enhanced growth response of strawberry to soil fumigation with methyl bromide/chloropicrin.

Research currently in progress during the 1998-99 growing season includes the following:

1. Continued experiments on the microbial mechanisms by which strawberry growth and yield respond to soil fumigation, with further testing of potentially beneficial microorganisms.
2. A comparison of broadcast and bed fumigations, and further bed fumigation experiments on chloropicrin with and without Telone added. In cooperation with Husein Ajwa and Tom Trout, ARS-USDA, this includes the use of fumigants at relatively low rates, applied by shank injection or through drip lines as emulsions, and a comparison of standard polyethylene to a high-barrier plastic mulch.
3. Experiments on the possible use of ozone as a soil fumigant, both with and without the addition of beneficial microorganisms.
4. Experiments funded by the Statewide UC IPM Program on cultural management of Verticillium wilt in strawberry production, including crop rotations, organic soil amendments, determinations of inoculum thresholds for disease and yield losses, and development of improved methods to screen strawberry varieties for genetic tolerance or resistance to Verticillium wilt.

## Evaluation of Drip Irrigation Systems to Deliver Alternative Fumigants to Methyl Bromide for Strawberry Production

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**Objectives:** to determine the distribution and efficacy of Telone C35 EC, Vapam, and Chloropicrin applied through drip irrigation systems, and to develop optimum irrigation parameters for strawberry production under the alternative fumigants.

Variables that are being evaluated include fumigants application rate, amount of water used to apply the fumigants, and application of combinations of fumigants.

### FUMIGANT APPLICATION TREATMENTS

| Trt# | Treatment Description |
|---|---|
| 1 | Untreated control |
| 2 | MeBr/Chloropicrin bed shank injection @ 425 lb/ac (245 lb/ac-bed) |
| 3 | Telone/Chloropicrin (Telone C35) bed shank injection @ 425 lb/ac |
| 4 | Telone C35 EC drip applied @ 425 lb/ac in 15 mm net irrigation |
| 5 | Telone C35 EC drip applied @ 425 lb/ac in 25 mm net irrigation |
| 6 | Telone C35 EC drip applied @ 425 lb/ac in 35 mm net irrigation |
| 7 | Telone C35 EC drip applied @ 255 lb/ac in 25 mm net irrigation |
| 8 | Vapam (42%) drip applied @ 75 gal/ac in 25 mm net irrigation |
| 9 | Vapam (42%) drip applied @ 75 gal/ac in 35 mm net irrigation |
| 10 | Vapam (40%) drip applied @ 50 gal/ac in 25 mm net irrigation |
| 11 | Telone C35 EC @ 255 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 12 | Chloropicrin @ 160 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 13 | Chloropicrin ~ 160 lb/a~ drip applied in 25 mm net irrigation |

### IRRIGATION TREATMENTS

Strawberry yield in Telone C35 bed shank injection (at 425 lb/ac and 255 lb/ac) will be irrigated by three irrigation amounts [75% (Low), 100% (Med.), and 125% (High) of crop evapotranspiration].

MBA 1998-99

MBA 98 plots (Fumigated Sept 6-8, 1998)

| # | Irrig | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | (T13)-PicMw (25 mm) | (T9)-MvHw (35 mm) | (T5)-HtMw (25 mm) | (T12)-(Pic+Mv)Mw |
| 1 | M | Low Telone C35 Shank | High Telone C35 Shank | | (T7)-MtMw (25 mm) | (T8)-HvMw (25 mm) | (T10)-MvMw (25 mm) | (T2)-MeBr/Pic Shank |
| 2 | L | Low Telone C35 shank | High Telone C35 Shank | | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) | (T13)-PicMw (25 mm) | (T6)-HtHw (35 mm) |
| 3 | H | Low Telone C35 shank | High Telone C35 Shank | | (T4)-HtLw (15 mm) | (T12)-(Pic+Mv)Mw | (T8)-HvMw (25 mm) | (T9)-MvHw (35 mm) |
| 4 | H | High Telone C35 Shank | Low Telone C35 shank | | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank | (T5)-HtMw (25 mm) |
| 5 | M | High Telone C35 Shank | Low Telone C35 shank | | (T11)-(Mt+Mv)Mw | (T1)-Untreated control | (T12)-(Pic+Mv)Mw | (T4)-HtLw (15 mm) |
| 6 | L | High Telone C35 Shank | Low Telone C35 shank | | (T9)-MvHw (35 mm) | (T3)-Telone/Pic Shank | (T1)-Untreated control | (T11)-(Mt+Mv)Mw |
| 7 | M | Low Telone C35 shank | High Telone C35 Shank | | (T1)-Untreated control | (T4)-HtLw (15 mm) | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) |
| 8 | H | Low Telone C35 shank | High Telone C35 Shank | | (T5)-HtMw (25 mm) | (T13)-PicMw (25 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank |
| 9 | L | Low Telone C35 shank | High Telone C35 Shank | | (T12)-(Pic+Mv)Mw | (T2)-MeBr/Pic Shank | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) |
| 10 | M | High Telone C35 Shank | Low Telone C35 shank | | (T10)-MvMw (25 mm) | (T11)-(Mt+Mv)Mw | (T9)-MvHw (35 mm) | (T8)-HvMw (25 mm) |
| 11 | L | High Telone C35 Shank | Low Telone C35 shank | | (T3)-Telone/Pic Shank | (T6)-HtHw (35 mm) | (T11)-(Mt+Mv)Mw | (T1)-Untreated control |
| 12 | H | High Telone C35 Shank | Low Telone C35 shank | | (T8)-HvMw (25 mm) | (T5)-HtMw (25 mm) | (T4)-HtLw (15 mm) | (T13)-PicMw (25 mm) |
| | | 35 ft | 35 ft | | 31 ft | 31 ft | 31 ft | 31 ft |

## Cultural and Genetic Strategies for Management of Phytophthora on California Strawberries

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**Background and Project Significance**

Root or crown infections by *Phytophthora* species can cause plant stunting or collapse and reduce profitability of nursery and fruit production. The infections and disease development are favored by mild to moderate temperatures and periods of soil water saturation. *Phytophthora* species are soilborne, but they are spread readily by plants, soil, or water. Methyl bromide/chloropicrin mixtures effectively reduce populations of *Phytophthora*, but alternative management approaches will increase in importance as methyl bromide (MB) use is restricted.

**Highlights of 1997/98 work**

**Field evaluations of resistance to Phytophthora.** The UC strawberry breeding program has adopted field screens for ongoing evaluations of genetic resistance to Verticillium wilt, but similar evaluations are just beginning for Phytophthora crown rot. We are developing the required screening methods and, at the same time, evaluating resistance of recently released California cultivars to *P. cactorum* and *P. citricola*. We intend to provide growers with replicated assessments of Phytophthora resistance on newly released strawberry cultivars and furnish breeders with reliable methods for future evaluations of Phytophthora resistance in their programs.

Last year at Monterey Bay Academy, soil infestation and plant dip inoculations were tested for use in the screens. Cultivar Pajaro was used as a susceptible standard and developed early-season stunting and late-season collapse when planted in holes infested with *P. cactorum* or *P. citricola*. Decreasing the amount of inoculum by 50% or moving it a few inches away from the plant crown reduced stunting and subsequent mortality. Plant dipping in liquid *Phytophthora* suspension provided a faster, simpler inoculation procedure than soil infestation, but results with the former have been less reliable to date.

The soil infestation procedure was applied to assess resistance of Aromas, Camarosa, Diamante, and Pajaro. *P. cactorum* caused significant early-season stunting in all four cultivars (Fig. 1-A), but as the season progressed, only Diamante and Pajaro suffered much mortality (Fig. 1-B). The marketable yields of Aromas and Camarosa in *P. cactorum* infested soil were 81% and 64% of their non-inoculated controls, whereas those of Diamante and Pajaro were only 35-36% of their controls, (Fig. 1-C). Overall, *P. citricola* was less damaging than *P. cactorum* on Diamante and Pajaro and did not reduce yields of Aromas (Fig. 1A-C). Additional experiments are underway in an experimental nursery area at the Wolfskill facility. We are determining if Phytophthora resistance screening can be accomplished there as well as at MBA.

**Greenhouse evaluations of resistance to *Phytophthora*.** In past years, greenhouse screens of resistance to *Phytophthora* have given mixed results when repeated at different times of the year. Our goals with greenhouse experiments are 1) to improve their reliability and 2) to test their validity against field results. Results of 1998 experiments on greenhouse screening methods indicated that:

- 24-hr weekly soil-water saturation periods caused twice as much damage as 48-hr biweekly wetting periods.
- 9- or 13-wk. periods were sufficient for crown rot development; a 5-wk. period was too short.
- Mineral or peat/sand potting media were similarly conducive to root and crown rot.
- Artificial pre-inoculation chilling did not influence susceptibility to Phytophthora crown rot.
- Plant dip inoculations worked as well as soil infestation inoculations.
- Pot size could be reduced without significantly affecting results.

**Irrigation-Phytophthora interactions at MBA.** Careful irrigation water management can aid control of many diseases caused by *Phytophthora*, because soil saturation favors dispersal and infection by *Phytophthora* spores. We are investigating the influence of irrigation intensity on development of Phytophthora crown rot. At MBA, the duration of every-other-day drip irrigations was varied during April-July so that amounts of water applied approximated 50%, 100%, or 200% of evapotranspiration (ET) demand in non-infested soil and soil infested with a *P. cactorum* + *P. citricola* mixture. In the infested plots, mortality was lowest and yield greatest under the 200% ET regime (Fig. 1-D). We suspect that high amounts of rainfall last year favored early-season infection by Phytophthora before differential irrigation was imposed. Slight water stress under the "0.5 ET" irrigation regime may have hastened collapse of already-infected plants. We are repeating the work this year.

**Future directions**

The overall goal is to develop and facilitate cultural, genetic, and chemical strategies for management of Phytophthora diseases on California strawberries. These strategies, along with similar ones for other soilborne disease complexes, should help lessen dependence upon methyl bromide fumigation. Work in progress includes:

- Enlarged field screening tests for Phytophthora resistance at MBA with cultivars Aromas, Camarosa, Diamante, Gaviota, Pacific, Pajaro, and Parker (last two used as standards).
- Evaluation of a Phytophthora resistance screening protocol at Wolfskill for the UC strawberry program.
- Determining the degree of agreement between field and greenhouse assessments of resistance to *Phytophthora*.
- Determining effects of irrigation intensity on development of Phytophthora crown rot.
- Determining efficacy of Ridomil Gold EC and Aliette WDG for control of Phytophthora crown rot (field experiment at MBA).

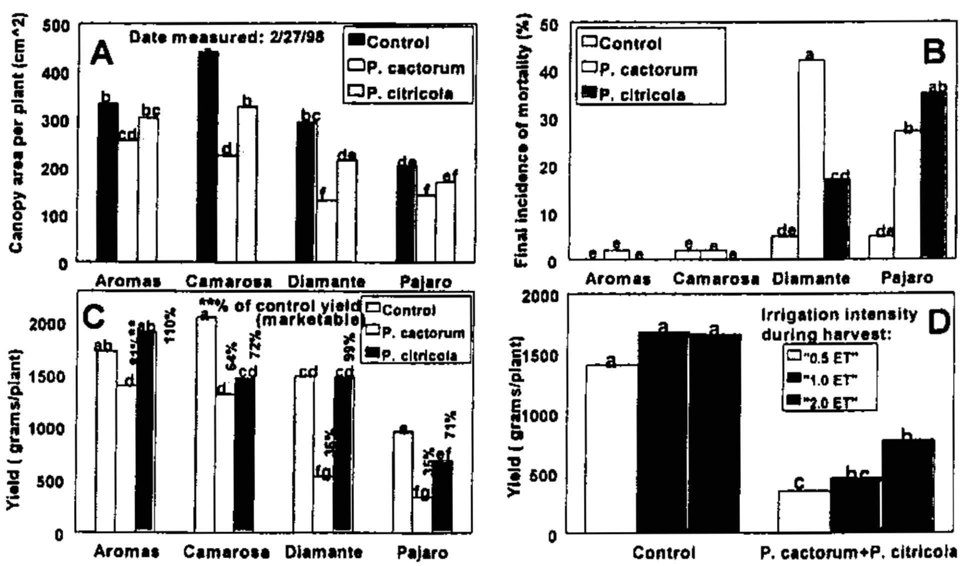


**Figure 1.** Relative susceptibility of some strawberry cultivars to: **A**, early season stunting; **B**, plant mortality, and **C**, yield depression caused by *Phytophthora cactorum* and *P. citricola*. **D**, effects of *P. cactorm* + *P. citricola* and irrigation intensity during harvest on total marketable fruit yield of cultivar Diamante.

## BACTERIAL ANGULAR LEAFSPOT (*Xanthomonas fragariae*) RESEARCH (1998-1999)

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Bacterial angular leafspot disease (ALSD) of strawberry is caused by *Xanthomonas fragariae* (*Xf*). Incidence of ALSD has been widespread in California nurseries and fruit production fields in all major strawberry-producing regions of the state in recent years. Xf is also a quarantine pest that is regulated by state, federal, and international phytosanitary regulations. The economic effects of ALSD on plant growth, vigor, productivity, and yield, under California conditions are not well documented.

Infection and disease development are favored by cool, wet conditions. Although chemical control of ALSD is generally ineffective, sanitation (i.e. pathogen exclusion and/or eradication) is an important aspect of ALSD management. However, implementation of effective sanitary practices to exclude or eliminate Xf is dependent upon understanding the epidemiology of Xf in California, and upon the ability to rapidly and reliably detect Xf in infected, but clinically asymptomatic, plant material. Sources of infection in California nurseries and fruit production fields have not been clearly identified.

Current research is focused on disease control (genetic resistance, chemical control), pathogen biology and disease epidemiology (primarily in asymptomatic planting stock). This work is being done at the Monterey Bay Academy in Watsonville and at DB Specialty Farms in Santa Maria.

**Experiment 1.** Effect of preplant dip treatments on the incidence of ALSD, plant vigor, and yield. The following treatments were used: untreated control, hot water (47.5 C for 10 min), hot water + Kocide, or hot water + Tenncop. Results of 1998 trial showed that hot water, alone or in combination with bactericides, did not cause any mortality or visible phytotoxicity to the transplants. Treated plants did not significantly differ in disease severity, plant vigor, and yield of marketable fruits from untreated plants.

**Experiment 2.** Germplasm evaluation for susceptibility to angular leaf spot. There is a broad range of relative ALSD incidence on all short day and long day cultivars evaluated to date at Watsonville. There is some overlap of, and no statistically significant differences between, the ALSD ratings of most of the cultivars. However, the short day cultivars generally develop less ALSD than day neutral cultivars under the conditions of Watsonville. Among the cultivars evaluated, the ALSD ratings for Anaheim and Parker are significantly lower than those of other cultivars. On the other hand, the ALSD ratings for Diamante and Pacific are significantly higher than those of other cultivars. In 1999, these and other cultivars are being evaluated in Watsonville and Santa Maria.

**Experiment 3.** Effect of angular leaf spot on plant vigor and fruit production. This experiment is being conducted to assess the relative vigor and production of planting stocks harvested from non-diseased and ALSD-affected (i.e. naturally infected) mother plants from a high elevation nursery in California. Based on last years' results, there were no significant differences in ALSD development, overall plant growth and production of *artificially* infected (inoculated and visibly infected at planting time) and healthy (not inoculated, with no visible ALS symptoms at planting time) planting stocks. Accordingly, the effect(s) of *naturally* infected planting stock on these parameters is being determined in 1999 in Watsonville and in Santa Maria.

**Experiment 4.** Endophytic and Epiphytic *Xanthomonas fragariae*. Last years' preliminary results showed that *Xf* survived on the surface of strawberry leaves throughout most of the growing season. The level of epiphytic *Xf* recovered from leaves was, in general, consistent with the relative cultivar resistance/susceptibility to ALSD.

# Management of Root Diseases and Rhizosphere Ecology of Strawberry

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Several approaches are currently under evaluation for management of root diseases of strawberry, including evaluation of alternative pesticides, alteration of crop rotation practices. and identifying host cultivars that are less susceptible to disease. A better understanding of specifically which pathogens are responsible for yield losses when plants are grown in poorly or nonfumigated fields will assist in developing these disease control strategies. In addition, a more comprehensive understanding of the types of organisms colonizing the roots of plants grown in fumigated compared to nonfumigated soils also would be helpful for developing alternative pest control strategies. This would include determining if detrimental root colonizers contribute to yield reductions in nonfumigated soil, as well as the identification of beneficial root colonizing organisms that might be capable of improving root health (either directly by stimulating root growth or indirectly by protecting against soilborne pathogens). The long-term objective of this project is to integrate the results of this research with ongoing trials evaluating alternative soil fumigants, crop rotation practices, and a screening program to develop biological control agents.

**1) Evaluation of pathogen involvement in growth and yield reduction.** A number of fungi have been recovered from necrotic roots of plants grown in nonfumigated soils collected from various farms in the central coastal area and are under evaluation for their effect on strawberry plants. The most emphasis has been placed on ***Pythium*** spp. and binucleate ***Rhizoctonia,*** although ***Cylindrocarpon*** and other fungal pathogens have been investigated as well. Trials conducted in greenhouse/growth chamber tests revealed different levels of virulence for the species examined; with some having negligible effects on root health. Trials assessing tolerance of different host cultivars to the most virulent pathogens are in progress. Field evaluations to determine the involvement of some of these pathogens on plant growth and yield reductions are included in this year' s field plots.

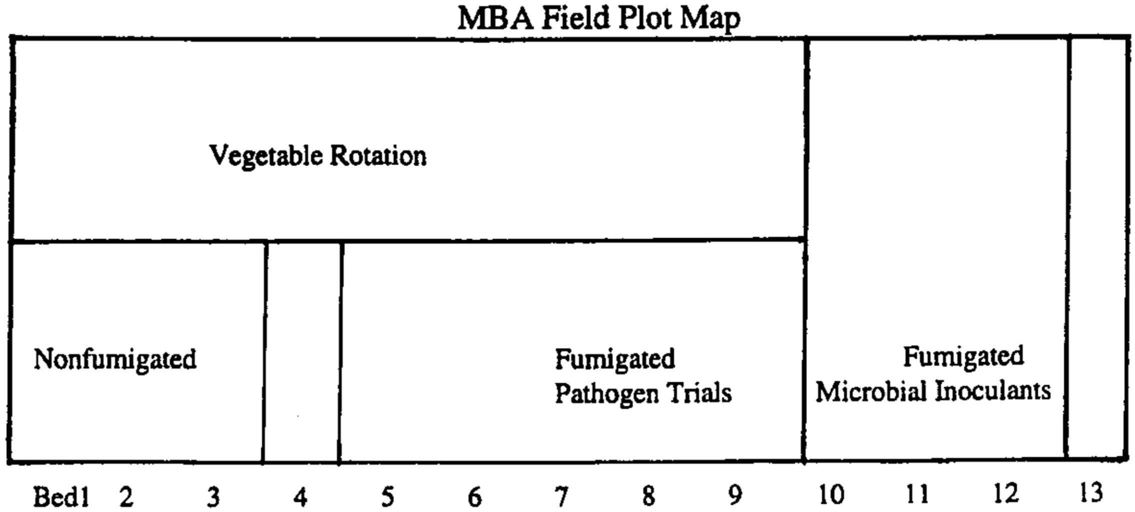
**2) The effect of crop rotation on pathogen population densities and strawberry root diseases.** A number of *strawbeny* root pathogens have a broad host range and are capable of infecting other crops, so in the absence of effective soil fumigation crop rotation can have a significant influence on maintaining populations of soilborne pathogens. Field trials evaluating the influence of rotation with broccoli, Brussels sprouts, or lettuce on the population dynamics of *Pythium* spp. and *Verticillium dahliae* are in progress at MBA. The field was cropped in vegetable rotation in the 1997 season, strawberry (Selva) in the 1998 season, and is presently in vegetable rotation. After harvesting the vegetable crops, the stubble was mowed with a flail mower, allowed to dry on the soil surface for several days and then incorporated into the soil. Two cropping cycles were planted for broccoli and lettuce and one for Brussels sprouts. While cropping practices had no consistent influence of population densities of *Pythium* spp., broccoli and Brussels sprouts reduced V. *dahliae* inoculum densities by 80-90% (to a final inoculum density of 1-2 microsclerotia/g soil). Although the market yield for all rotation treatments was significantly below the MB + Pic fumigated controls, strawberry grown in the broccoli rotation plots had only a 23% reduction in yield compared to Brussels sprouts and lettuce, which had yield reductions of 31% and 39%, respectively. Similar experiments (rotation with broccoli, cauliflower, or lettuce) also are underway at the Spence Rd. plots in Salinas. Cooperators on this project include Drs. Subbarao and Shetty and Steve Koike.

**3) Influence of root colonizers of root health, plant growth, and yield.** Preliminary investigations on the population structure and seasonal fluctuations of fungal, bacterial, and actinomycete root colonizers has been done for plants grown in fumigated and nonfumigated soils. A number of the recovered isolates have been evaluated for their effect on shoot and root growth in greenhouse/growth chamber trials. While most isolates had no effect on plant growth, some were identified that increased either shoot growth (up to a 40% increase), root growth (up to a 138% increase), or a general stimulatory effect on both shoot and root growth. Several isolates also were identified that had inhibitory effects on root growth (up to a 26% reduction). Trials last year at the USDA test site off of Spence Rd. in Salinas in nonfumigated soil identified several beneficial isolates that significantly increased yield over the untreated control plants (one isolate gave a 35.5% increase in marketable yield) while other isolates appeared to have a detrimental effect on yield. Trials are in progress this season at MBA in fumigated soil to evaluate the influence of these isolates on plant growth and yield when plants are grown in the absence of soilborne pathogens. Trials evaluating the efficacy of several commercial biological control agents are underway as well.

**Additional experimentation related to the plots at MBA**

- Field surveys of the central coastal production area to identify which root pathogens are present in the area and determine if there are fluctuations in the incidence of root infection during the production cycle.
- Greenhouse/growth chamber trials are underway to evaluate the susceptibility of 17 strawberry varieties to the root pathogens *Pythium* (several different species) and binucleate *Rhizoctonia* (3 anastomosis groups).
- Several field trials in progress at the USDA test plots off of Spence Rd. in Salinas. This site is naturally infested with a number of root pathogens (*Pythium*, binucleate *Rhizoctonia*, *Cylindrocarpon* spp., etc) with the exception of Verticillium wilt.
    - Evaluations of strawberry variety performance when plants are grown in nonfumigated compared to fumigated soil; currently 14 varieties are under evaluation.
    - Evaluating the influence of crop rotation on pathogen populations and disease severity; rotation crops include broccoli, cauliflower, and lettuce.
    - Evaluating the influence of microbial inoculants on plant growth and yield in fumigated and nonfumigated soil.
    - Evaluation of commercial biological control agents for enhanced plant growth and yield in fumigated and nonfumigated soil.

MBA Field Plot Map



# Summary of Recent Research on Verticillium wilt in High Elevation Strawberry Nurseries


| | | |
|---|---|---|
| T.R. Gordon | K.D. Larson | D.V. Shaw |
| Plant Pathology | Pomology Department | Pomology Department |
| U.C. Davis | U.C. Davis | U.C. Davis |


During 1998, research continued on the use of chemical fumigants and cover crops for control of Verticillium wilt, caused by *Verticillium dahliae*, in high elevation strawberry nurseries. Six treatments were tested in a field experiment, which was initiated in 1995; each treatment had three replications, for a total of 18 plots. In one of these treatments, plots were kept fallow, while the other five treatments all had fall crops of rye in 1995 and 1996. Treatment two included spring plantings of mustard (canola), in 1996 and 1997, following incorporation of the fall rye crop. The mustard crops were cut and incorporated in the summer, and tarped for approximately one month. Treatments three through five had two years in rye followed by a chemical fumigation in August of 1997: either methyl bromide:chloropicrin (2:1) @ 350 pounds/acre, chloropicrin alone @ 250 pounds/acre, or C-35 (35% chloropicrin and 65% telone) @ 380 pounds/acre. The last treatment had two years in rye and no fumigation.

In April of 1998, all plots were planted to two strawberry cultivars, Camarosa and Selva. All fumigation treatments appeared to be equally effective in reducing soil populations of *V. dahliae*, which were undetectable (< 1 microsclerotium/gram of soil) in all the fumigated plots. Of the non-fumigated treatments, fallow had the lowest levels of *V. dahliae* (11 microsclerotia/gram), whereas the rye only and the rye/mustard treatments both had an average of 20 microsclerotia/gram. No disease was detectable in any of the fumigated plots. For Camarosa, 52, 56, and 76% of the plants had symptoms of Verticillium wilt in the rye, fallow, and rye/mustard treatments, respectively. For Selva, in both the rye and rye/mustard treatments, 87% of the plants were symptomatic, whereas 73% of the plants in fallowed plots had disease symptoms.

In summary, all the chemical fumigants provided adequate control of Verticillium wilt; whereas none of the non-chemical treatments was satisfactory. It should also be noted that fumigation experiments in previous years have shown less complete control with non-methyl bromide treatments. Thus chloropicrin alone or combined with telone may prove to be less consistent than the standard methyl bromide:chloropicrin combination.

In terms of runner production in the nursery, methyl bromide: chloropicrin was the best treatment. For Selva, plots receiving this treatment produced an average of 1331 runners per plot. The C-35 treatment (1117 runners/plot) was not significantly different from methyl bromide:chlorpicrin but chloropicrin alone was significantly worse (920 runners/plot). Similar results were obtained for Camarosa, although in this case, the differences between the fumigants were not statistically significant. Overall, the results indicate that the fumigants differ somewhat due to factors other than Verticillium. That is, although Verticillium wilt was not a problem in any of the fumigated plots, there were differences in productivity. This may reflect the activity of microorganisms in the soil that were differentially affected by the fumigants.

Runners representative of each nursery treatment have been planted at the South Coast field station (Camarosa) and at Watsonville (Selva) in order to evaluate any carry-over effects of the nursery treatments. Previous findings suggest that plants from nursery plots fumigated with chloropicrin or C-35 will not perform as well as those from methyl bromide:chloropicrin fumigated ground.

During 1999 we will also be evaluating the effects of post-harvest chilling treatments on plants from a high elevation nursery. Results from last year indicated that extended chilling periods significantly reduced the survival of *Verticillium dahliae* in infected runner plants. For example, in Selva stored at 34 F for 32 days, the pathogen was virtually eliminated. As a result, based on the cumulative fruit yield, there was no difference between plants from fumigated nursery plots and those from the same plots, which were inoculated prior to planting (at the nursery). However, fruit production by plants from non-fumigated plots never reached the levels of the plants from fumigated nursery plots, even with maximum chilling. This indicates that carry-over effects resulting from factors other than Verticillium are not negated by exposure to low temperatures.

Comparable effects were not been observed for Camarosa, where chilling was correlated with only a modest reduction in the incidence of Verticillium. However, because Camarosa is typically planted soon after harvest, the longest chilling period we tested was 17 days. Currently we are looking at the effects of longer chilling periods in Camarosa, to determine if this explains the difference between the two varieties. Preliminary indications are that Verticillium levels remain high, even when Camarosa is stored for >30 days. Thus, varietal differences may be important as well. We are also testing the effects of a late nursery harvest of Camarosa, to coincide with Selva, to determine if this contributes to a difference in the effects of post-harvest chilling. To gain further insight into the influence of variety on the chilling response, we have included Diamante in our current year's experiment, to provide a day neutral variety for comparison with Selva.

## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Watsonville, California - Site #1

| Treatment | Tarp | Application |
|---|---|---|
| Chloropicrin EC 24 gallons/acre | Standard tarp | Drip |
| Chloropicrin EC 24 gallons/acre | High barrier tarp | Drip |
| **Telone C35 EC 35 gallons/acre** | **Standard tarp** | Drip |
| **Telone C35 EC 35 gallons/acre** | **High barrier tarp** | Drip |
| Cholorpicrin 120 lbs acre | Standard tarp | Shank |
| Chloropicrin 200 lbs/acre | Standard tarp | Shank |
| Cholorpicrin 120 lbs acre | High barrier tarp | Shank |
| Chloropicrin 200 lbs/acre | High barrier tarp | Shank |
| Telone C35 210 lbs/acre | Standard tarp | Shank |
| **Telone C35 350 lbs/acre** | **Standard tarp** | Shank |
| Telone C35 210 lbs/acre | High barrier tarp | Shank |
| **Telone C35 350 lbs/acre** | **High barrier tarp** | Shank |
| **MBr/Pic 67/33** | **Standard tarp** | Shank |

250'

## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Watsonville, California - Site #2

| | |
|---|---|
| **Telone C35 EC 35 gallons/acre**<br>**Standard GREEN tarp** | **Drip** |
| **Telone C35 EC 35 gallons/acre**<br>**Standard clear tarp** | **Drip** |
| Telone C35 EC 35 gallons/acre<br>High barrier clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre<br>Standard clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre<br>High barrier clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre<br>Standard GREEN tarp | Drip |
| **MBr/Pic 67/33**<br>**Standard GREEN tarp** | **Shank** |

215'

The below treatments are located on another section of the farm.

| | |
|---|---|
| **Telone C35 350 lbs/acre**<br>**Standard GREEN tarp** | **Shank** |
| Cholorpicrin 200 lbs/acre<br>Standard GREEN tarp | Shank |

# Weeding data, 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials
## Trial location: Watsonville, California - Site #2

**Weeding data**

Minutes hand weeding 0.046 acres

| | Date | | | | Total[1] | | | |
|---|---|---|---|---|---|---|---|---|
| | 12/11/1999 | 1/5/1999 | 2/13/1999 | 3/7/1999 | Minutes | Hours | Cost ($) | $/acre |
| Telone C35 EC 35 gallons/acre, drip applied, green tarp | 20 | 5.5[2] | 5 | 6 | 31 | 0.5 | $3.36 | $73.01 |
| Cholorpicrin EC 24 gallons/acre, drip applied, green tarp | 30 | 5.5 | 5 | 6 | 46.5 | 0.8 | $5.04 | $109.51 |
| Cholorpicrin EC 24 gallons/acre, drip applied, VIF clear tarp | 90 | 15 | 49.5 | 23 | 177.5 | 3.0 | $19.23 | $418.03 |
| Telone C35 EC 35 gallons/acre, drip applied, VIF clear tarp | 170 | 15 | 10 | 24 | 219 | 3.7 | $23.73 | $515.76 |
| Cholorpicrin EC 24 gallons/acre, drip applied, standard clear tarp | 145 | 20 | 56 | 20 | 241 | 4.0 | $26.11 | $567.57 |
| Telone C35 EC 35 gallons/acre, drip applied, standard clear tarp | 165 | 50 | 20 | 47 | 282 | 4.7 | $30.55 | $664.13 |

1 This represents only a portion of the seasonal weeding costs.
2 This time essentially represents walking the length of the bed.

# Strawberry Methyl Bromide Alternatives Tour

# July 20-22, 1999

Sponsored by

**The California Strawberry Commission**
**California Strawberry Nurserymens Association**

**Tour Purpose**

Most of the attention given to methyl bromide and its alternatives has been focused on fruit production. The strawberry nurseries and the coastal fruit production areas actually compose the California strawberry industry; the industries are inextricably linked. Clean planting stock is imperative for successful (read 'economically viable') strawberry farming - this includes the current integrated pest management based strawberry fruit production system and organic strawberry fruit production. The July 20-22 tour has a fruit production/nursery focus. The idea behind the tour is to see how well methyl bromide alternatives fair relative to the standard treatment later in the California strawberry season in the Watsonville area, and then visit the low and high elevation nursery areas to give the tour attendees a first hand look at what is really involved in nursery production, constraints faced by both high and low nursery production, etc. One might ask, "There have been two tour this year, why have another?" As you know, in California strawberry production is almost continuous. Visiting trial sites at only one or two times in the year probably will leave one with misconceptions about farming under MeBr alternatives. Visiting sites during this July tour will allow the attendees to see first and how well methyl bromide alternatives fair relative to the standard later in the California strawberry season. Unfortunately there is not an entire week to conduct a tour from southern California to the nurseries in the far north of California, so the tour is focused on the Watsonville area and nurseries (low and high). The tour will also provide an avenue for the attendees to interact, discuss how federal, state and county entities interrelate and can cooperate in helping to solve the MeBr issue, and see the same things at the same time. At the end of the tour it is hoped that the tour attendees will have an appreciation and a shared understanding of the complexities of the strawberry production system in its entirety, and of the complexities involved in altering the California strawberry production system.

**Tour attendees**

Edwin Civerolo, USDA-ARS at UC Davis Department of Plant Pathology
Steve Fennimore UC Cooperative Extension, State Wide Weed Specialist
Curt Gaines, Lassen Canyon Nursery
Tom Gordon, UC Davis Department of Plant Pathology
Adolf Braun, Cal EPA, DPR
Daren Gee, D & B Specialty Farms
Kathleen Harvey, CDFA
Paul Helliker, Director, DPR
Rod Koda, Research Chairman, California Strawberry Commission
Skip Larson, Sierra Cascade Nursery
Kirk Larson, UC Davis Department of Pomology, SCFS
David Moeller, Agricultural Commissioner, Sant Cruz County
Mark Murai, CalBeri
Albert Paulus, UCR, UC Cooperative Extension
Miguel Ramos, Ramos Farms
David Riggs, President, California Strawberry Commission
Bill Thomas, USEPA
Tom Trout, USDA ARS Water Management Lab, Fresno
Ken Vick, USDA ARS NPS
Jim Wells, Consultant to CSC
Frank Westerlund, Research Director, California Strawberry Commission
Christopher Winterbottom, California Strawberry Commission

**Additional Attendees**

Dennis Matsuoka, Sierra Cascade Nursery
Curt Grimes, Lassen Canyon Nursery
Pete Ruffing, Dow AgroSciences
Martin O'Connor, Western Farm Services
Cheryl Sawyer, Dow AgroSciences
Ray Brinkmeyer, Dow AgroSciences
Dave Valcore, Dow AgroSciences
Jesse Richardson, Dow AgroSciences
Ryan Rislak, Dow AgroSciences
Massake Hassuike, Hokko du Brasil
John Busacca, Dow AgroSciences
Barbara Zapp, USDA-ARS
Carlos Rojas, Dow AgroSciences
Marion Myner, Del Monte
Phillip Schwab, USDA-CSREES
Jim Ralles, Klerks Plastics
Frank Martin, USDA
Jim Mueller, Dow AgroSciences
Roy Gingery, USDA-ARS
Bill Ito, Farmer
Jack Norton, IR-4
Doug Roby, Dow AgroSciences
Ron Harding, Dow AgroSciences
Irene Wallburm, Dow AgroSciences
Kirk Fowler, Trical
Deb Shatley, Dow AgroSciences
John Guthrie, Dow AgroSciences
Scott Mueller, Dow AgroSciences
Mark Bothard, Dow AgroSciences
Carlos Luis Rodrigues, Del Monte
Pablo Fernandez, Dow AgroSciences
Paul Niday, Trical
Hussein Ajwa, USDA-ARS
Mike Nelson, Plant Sciences Inc.
Cynthia Eayre, USDA-ARS

## The Watsonville/Strawberry Nurseries Tour Schedule

**July 19**

Tour attendees arrive in the Watsonville area. Transportation from local airports (Monterey/San Jose/San Francisco) to the Watsonville area.

**July 20**

| | |
|---|---|
| 0730 hours | Meet at the California Strawberry Commission |
| 0800 hours | Visit Watsonville strawberry farm to see MeBr alternatives. |
| 0900 hours | Visit California Strawberry Commission research site for MeBr alternatives. |
| 1030 hours | Visit Watsonville strawberry farm to see MeBr alternatives. |
| 1130 hours | Lunch |
| 1200 hours | Travel to low elevation nurseries in the Central Valley. |
| 1330 hours | Tour nursery screen, foundation, and expansion plots in Manteca. Tour trim shed and cooler, presentations on nursery production scheme, research data presentation on MeBr alternatives in nursery setting. |
| 1630 hours | Depart for Sacramento. |

**July 21**

| | |
|---|---|
| 0600 hours | Depart from Sacramento. |
| 0930 hours | Anderson, California – visit strawberry nursery lab and heat treatment facilities. |
| 1100 hours | Redding, California – visit strawberry nursery screenhouse and trimming facility. |
| 1400 hours | Mcdoel, California – lunch, visit nursery fumigation trials and planting stock production fields. |
| 1800 hours | Travel to lodgings in Mount Shasta. |

**July 22**

| | |
|---|---|
| 0800 hours | Travel (3.5 hours) from Mt. Shasta to Sacramento to catch flights in the mid to late afternoon. |

## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Watsonville, California - Site #2

| | | |
|---|---|---|
| **Telone C35 EC 35 gallons/acre** | **Standard GREEN tarp** | **Drip** |
| **Telone C35 EC 35 gallons/acre** | **Standard clear tarp** | **Drip** |
| Telone C35 EC 35 gallons/acre | High barrier clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre | Standard clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre | High barrier clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre | Standard GREEN tarp | Drip |
| **MBr/Pic 67/33** | **Standard GREEN tarp** | **Shank** |

215'

The below treatments are located on another section of the farm.

| | | |
|---|---|---|
| **Telone C35 350 lbs/acre** | **Standard GREEN tarp** | **Shank** |
| Cholorpicrin 200 lbs/acre | Standard GREEN tarp | Shank |

# Weeding data, 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials
# Trial location: Watsonville, California - Site #2

**Weeding data**

Minutes hand weeding 0.046 acres

| | Date | | | | Total[1] | | | |
|---|---|---|---|---|---|---|---|---|
| | 12/11/1999 | 1/5/1999 | 2/13/1999 | 3/7/1999 | Minutes | Hours | Cost ($) | $/acre |
| Telone C35 EC 35 gallons/acre, drip applied, green tarp | 20 | 5.5[2] | 5 | 6 | 31 | 0.5 | $3.36 | $73.01 |
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| Cholorpicrin EC 24 gallons/acre, drip applied, VIF clear tarp | 90 | 15 | 49.5 | 23 | 177.5 | 3.0 | $19.23 | $418.03 |
| Telone C35 EC 35 gallons/acre, drip applied, VIF clear tarp | 170 | 15 | 10 | 24 | 219 | 3.7 | $23.73 | $515.76 |
| Cholorpicrin EC 24 gallons/acre, drip applied, standard clear tarp | 145 | 20 | 56 | 20 | 241 | 4.0 | $26.11 | $567.57 |
| Telone C35 EC 35 gallons/acre, drip applied, standard clear tarp | 165 | 50 | 20 | 47 | 282 | 4.7 | $30.55 | $664.13 |

1 This represents only a portion of the seasonal weeding costs.
2 This time essentially represents walking the length of the bed.

# Response of Strawberry to Some Chemical and Cultural Alternatives to Methyl Bromide Fumigation of Soil

J. M. Duniway, C. L. Xiao, and W. D. Gubler
Department of Plant Pathology, University of California, Davis CA 95616

The experiments reported here are part of a larger project supported by the California Strawberry Commission, the California Department of Pesticide Regulation Pest Management Alliance Grant, and ARS-USDA to research chemical and nonchemical alternatives to methyl bromide for preplant fumigation of soil in strawberry production. Chemical alternatives to methyl bromide have been tested in replicated field experiments at the Monterey Bay Academy near Watsonville, CA. Strawberry was grown every year, *Verticillium dahliae* was present in the soil, and bed fumigation treatments were applied in early October of each year. Two-row beds were shaped, fumigated (two shanks/bed, 15-20 cm deep, rates given per unit of treated bed area, which is 58% of the total area), and covered with black plastic mulch. Selva was transplanted through the plastic mulch one month later. Conventional practices for annual strawberry production and pest management for the area were followed, including sprinkler irrigation initially and drip irrigation in the production season. Berries were picked for fresh market at least weekly for several months by normal grower practice.

All of the bed fumigation treatments used in 4 years of experiments increased yield significantly in comparison to nonfumigated soil. For example, yields in 1997 and 1998, respectively, relative to those obtained following standard bed fumigation with methyl bromide/chloropicrin (67/33% @ 325 lb/acre), were 117 and 76% for chloropicrin alone (300 lb/acre), 105 and 87% for Telone/chloropicrin (65/35% @ 425 lb/acre), or 66 and 45% for nontreated soil. Application of the Telone/chloropicrin mixture to beds at the same rate in a water emulsion through drip lines gave yields of 102 and 104% relative to those obtained on beds fumigated with methyl bromide/chloropicrin, while broadcast fumigation with methyl bromide/chloropicrin (67/33%, 315-330 lb/acre total area) gave relative yields of 112 and 96%. All fumigation treatments reduced *V. dahliae* populations in soil and effectively controlled weed growth through plant holes in the plastic mulch. The results show that bed fumigations with the materials used can be effective and that drip application of emulsified Telone/chloropicrin shows promise, but the specific methods of application need further research. The use of a virtually impermeable black plastic mulch (Bromotec Y681B, Lawson Mardon Packaging, U.K.) in 1998 improved yields on average by 16% over those obtained with a standard black polyethylene mulch in the bed fumigation treatments above, and with chloropicrin or Telone/chloropicrin applied at rates reduced by one third.

Four experiments on a broccoli-strawberry rotation on nonfumigated soils have been completed. At Davis, CA, where *V. dahliae* is absent, one year of fallow or one year of broccoli production did not increase subsequent strawberry yields over those obtained with continuous strawberry production. Fumigation with methyl bromide/chloropicrin in the same experiment increased strawberry yields 54-69%. At the Watsonville site with high populations of *V. dahliae* present, a one-year rotation with broccoli increased subsequent strawberry yields by 24-38% and one year of rye increased yield 18-44%, relative to continuous strawberry, all on nonfumigated soil. Yield increases following one-year rotations out of strawberry, however, were approximately half as large as those obtained by soil fumigation in the same site and years. Although current California strawberry varieties are all susceptible to Verticillium wilt, the relationship of disease incidence to initial populations of *V. dahliae* in soil differed significantly between the varieties Selva and Camarosa.

We are researching microbiological differences associated with the enhanced growth and productivity of strawberries in soils fumigated with methyl bromide/chloropicrin where the response is not due to control of known, major pathogens. Plants in fumigated soils consistently had higher root length densities and fewer dark roots than plants in nonfumigated soils. Relative to nonfumigated soils, total numbers of fungi are usually low for several months following fumigation. *Cylindrocarpon* spp. were isolated from 0.5-cm segments of strawberry roots grown in nonfumigated soils (mean frequency 14%) but not from roots grown in fumigated soils. *Pythium* spp. were more commonly isolated from roots in nonfumigated soils, with mean isolation

frequencies of 3 and 11% for fumigated and nonfumigated soils, respectively. *Rhizoctonia* spp. were frequently isolated from roots in both fumigated and nonfumigated soils. Pathogenicity of the predominant isolates of these fungi was tested on strawberry in the greenhouse. *Cylindrocarpon* spp. did not cause significant root rot, but some isolates caused significant reductions in shoot and root growth. *P. ultimum* caused root rot and growth reductions. Of the 14 binucleate isolates of*Rhizoctonia* spp. tested, four caused significant root rot and growth reductions, while three others caused only growth reductions. Total populations of bacteria in soil were not affected by fumigation, but fluorescent pseudomonads were significantly less 5 days after fumigation. Populations of fluorescent pseudomonads in soil, however, increased quickly following fumigation and were 10-1000 fold higher than in nonfumigated soils 10 days to 9 months after fumigation. Predominant isolates of fluorescent pseudomonads from the rhizosphere were tested for effects on strawberry growth in natural field soil in the greenhouse. The effects of individual isolates ranged from beneficial (increased shoot and root dry weights up to 72% and 162%, respectively) to deleterious (about 20% shoot or root reduction). *Pseudomonas fluorescens, P. putida* and *P. chlororaphis* were among the most predominant and beneficial rhizobacteria tested. The results suggest that reductions in deleterious fungi and increases in beneficial fluorescent pseudomonads contribute to the enhanced growth response of strawberry to soil fumigation with methyl bromide/chloropicrin.

Research currently in progress during the 1998-99 growing season includes the following:

1. Continued experiments on the microbial mechanisms by which strawberry growth and yield respond to soil fumigation, with further testing of potentially beneficial microorganisms.
2. A comparison of broadcast and bed fumigations, and further bed fumigation experiments on chloropicrin with and without Telone added. In cooperation with Husein Ajwa and Tom Trout, ARS-USDA, this includes the use of fumigants at relatively low rates, applied by shank injection or through drip lines as emulsions, and a comparison of standard polyethylene to a high-barrier plastic mulch.
3. Experiments on the possible use of ozone as a soil fumigant, both with and without the addition of beneficial microorganisms.
4. Experiments funded by the California Department of Pesticide Regulation Pest Management Alliance Grant and Statewide UC IPM Program on cultural management of Verticillium wilt in strawberry production, including crop rotations, organic soil amendments, determinations of inoculum thresholds for disease and yield losses, and development of improved methods to screen strawberry varieties for genetic tolerance or resistance to Verticillium wilt.

# Evaluation of Drip Irrigation Systems to Deliver Alternative Fumigants to Methyl Bromide for Strawberry Production

Husein Ajwa and Tom Trout, USDA-ARS
*Water Management Research Laboratory, Fresno, CA*

**Objectives:** to determine the distribution and efficacy of Telone C35 EC, Vapam, and Chloropicrin applied through drip irrigation systems, and to develop optimum irrigation parameters for strawberry production under the alternative fumigants.

Variables that are being evaluated include fumigants application rate, amount of water used to apply the fumigants, and application of combinations of fumigants.

## FUMIGANT APPLICATION TREATMENTS

| Trt# | Treatment Description |
|---|---|
| 1 | Untreated control |
| 2 | MeBr/Chloropicrin bed shank injection @ 425 lb/ac (245 lb/ac-bed) |
| 3 | Telone/Chloropicrin (Telone C35) bed shank injection @ 425 lb/ac |
| 4 | Telone C35 EC drip applied @ 425 lb/ac in 15 mm net irrigation |
| 5 | Telone C35 EC drip applied @ 425 lb/ac in 25 mm net irrigation |
| 6 | Telone C35 EC drip applied @ 425 lb/ac in 35 mm net irrigation |
| 7 | Telone C35 EC drip applied @ 255 lb/ac in 25 mm net irrigation |
| 8 | Vapam (42%) drip applied @ 75 gal/ac in 25 mm net irrigation |
| 9 | Vapam (42%) drip applied @ 75 gal/ac in 35 mm net irrigation |
| 10 | Vapam (40%) drip applied @ 50 gal/ac in 25 mm net irrigation |
| 11 | Telone C35 EC @ 255 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 12 | Chloropicrin @ 160 lb/ac + Vapam (40%) @ 50 gal/ac simultaneously drip applied in 25 mm net irrigation |
| 13 | Chloropicrin ~ 160 lb/a~ drip applied in 25 mm net irrigation |

## IRRIGATION TREATMENTS

Strawberry yield in Telone C35 bed shank injection (at 425 lb/ac and 255 lb/ac) will be irrigated by three irrigation amounts [75% (Low), 100% (Med.), and 125% (High) of cropevapotranspiration].

MBA 1998-99

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | MBA 98 plots (Fumigated Sept 6-8, 1998) | | | | | |
| | Irrig | | | | | | | |
| # | | | | | (T13)-PicMw (25 mm) | (T9)-MvHw (35 mm) | (T5)-HtMw (25 mm) | (T12)-(Pic+Mv)Mw |
| 1 | M | Low Telone C35 Shank | High Telone C35 Shank | | (T7)-MtMw (25 mm) | (T8)-HvMw (25 mm) | (T10)-MvMw (25 mm) | (T2)-MeBr/Pic Shank |
| 2 | L | Low Telone C35 shank | High Telone C35 Shank | | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) | (T13)-PicMw (25 mm) | (T6)-HtHw (35 mm) |
| 3 | H | Low Telone C35 shank | High Telone C35 Shank | | (T4)-HtLw (15 mm) | (T12)-(Pic+Mv)Mw | (T8)-HvMw (25 mm) | (T9)-MvHw (35 mm) |
| 4 | H | High Telone C35 Shank | Low Telone C35 shank | | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank | (T5)-HtMw (25 mm) |
| 5 | M | High Telone C35 Shank | Low Telone C35 shank | | (T11)-(Mt+Mv)Mw | (T1)-Untreated control | (T12)-(Pic+Mv)Mw | (T4)-HtLw (15 mm) |
| 6 | L | High Telone C35 Shank | Low Telone C35 shank | | (T9)-MvHw (35 mm) | (T3)-Telone/Pic Shank | (T1)-Untreated control | (T11)-(Mt+Mv)Mw |
| 7 | M | Low Telone C35 Shank | High Telone C35 Shank | | (T1)-Untreated control | (T4)-HtLw (15 mm) | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) |
| 8 | H | Low Telone C35 shank | High Telone C35 Shank | | (T5)-HtMw (25 mm) | (T13)-PicMw (25 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank |
| 9 | L | Low Telone C35 Shank | High Telone C35 Shank | | (T12)-(Pic+Mv)Mw | (T2)-MeBr/Pic Shank | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) |
| 10 | M | High Telone C35 Shank | Low Telone C35 shank | | (T10)-MvMw (25 mm) | (T11)-(Mt+Mv)Mw | (T9)-MvHw (35 mm) | (T8)-HvMw (25 mm) |
| 11 | L | High Telone C35 Shank | Low Telone C35 shank | | (T3)-Telone/Pic Shank | (T6)-HtHw (35 mm) | (T11)-(Mt+Mv)Mw | (T1)-Untreated control |
| 12 | H | High Telone C35 Shank | Low Telone C35 shank | | (T8)-HvMw (25 mm) | (T5)-HtMw (25 mm) | (T4)-HtLw (15 mm) | (T13)-PicMw (25 mm) |
| | | 35 ft | 35 ft | | 31 ft | 31 ft | 31 ft | 31 ft |

# Cultural and Genetic Strategies for Management of Phytophthora on California Strawberries

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## Background and Project Significance

Root or crown infections by *Phytophthora* species can cause plant stunting or collapse and reduce profitability of nursery and fruit production. The infections and disease development are favored by mild to moderate temperatures and periods of soil water saturation. *Phytophthora* species are soilborne, but they are spread readily by plants, soil, or water. Methyl bromide/chloropicrin mixtures effectively reduce populations of *Phytophthora*, but alternative management approaches will increase in importance as methyl bromide (MB) use is restricted.

## Highlights of 1997/98 work

**Field evaluations of resistance to Phytophthora.** The UC strawberry breeding program has adopted field screens for ongoing evaluations of genetic resistance to Verticillium wilt, but similar evaluations are just beginning for Phytophthora crown rot. We are developing the required screening methods and, at the same time, evaluating resistance of recently released California cultivars to *P. cactorum* and *P. citricola*. We intend to provide growers with replicated assessments of Phytophthora resistance on newly released strawberry cultivars and furnish breeders with reliable methods for future evaluations of Phytophthora resistance in their programs.

Last year at Monterey Bay Academy, soil infestation and plant dip inoculations were tested for use in the screens. Cultivar Pajaro was used as a susceptible standard and developed early-season stunting and late-season collapse when planted in holes infested with *P. cactorum* or *P. citricola*. Decreasing the amount of inoculum by 50% or moving it a few inches away from the plant crown reduced stunting and subsequent mortality. Plant dipping in liquid *Phytophthora* suspension provided a faster, simpler inoculation procedure than soil infestation, but results with the former have been less reliable to date.

The soil infestation procedure was applied to assess resistance of Aromas, Camarosa, Diamante, and Pajaro. *P. cactorum* caused significant early-season stunting in all four cultivars (Fig. 1-A), but as the season progressed, only Diamante and Pajaro suffered much mortality (Fig. 1-B). The marketable yields of Aromas and Camarosa in *P. cactorum* infested soil were 81% and 64% of their non-inoculated controls, whereas those of Diamante and Pajaro were only 35-36% of their controls, (Fig. 1-C). Overall, *P. citricola* was less damaging than *P. cactorum* on Diamante and Pajaro and did not reduce yields of Aromas (Fig. 1A-C). Additional experiments are underway in an experimental nursery area at the Wolfskill facility. We are determining if Phytophthora resistance screening can be accomplished there as well as at MBA.

**Greenhouse evaluations of resistance to *Phytophthora*.** In past years, greenhouse screens of resistance to *Phytophthora* have given mixed results when repeated at different times of the year. Our goals with greenhouse experiments are 1) to improve their reliability and 2) to test their validity against field results. Results of 1998 experiments on greenhouse screening methods indicated that:

- 24-hr weekly soil-water saturation periods caused twice as much damage as 48-hr biweekly wetting periods.
- 9- or 13-wk. periods were sufficient for crown rot development; a 5-wk. period was too short.
- Mineral or peat/sand potting media were similarly conducive to root and crown rot.
- Artificial pre-inoculation chilling did not influence susceptibility to Phytophthora crown rot.
- Plant dip inoculations worked as well as soil infestation inoculations.

- Pot size could be reduced without significantly affecting results.

**Irrigation-Phytophthora interactions at MBA.** Careful irrigation water management can aid control of many diseases caused by *Phytophthora*, because soil saturation favors dispersal and infection by *Phytophthora* spores. We are investigating the influence of irrigation intensity on development of Phytophthora crown rot. At MBA, the duration of every-other-day drip irrigations was varied during April-July so that amounts of water applied approximated 50%, 100%, or 200% of evapotranspiration (ET) demand in non-infested soil and soil infested with a *P. cactorum* + *P. citricola* mixture. In the infested plots, mortality was lowest and yield greatest under the 200% ET regime (Fig. 1-D). We suspect that high amounts of rainfall last year favored early-season infection by Phytophthora before differential irrigation was imposed. Slight water stress under the "0.5 ET" irrigation regime may have hastened collapse of already-infected plants. We are repeating the work this year.

## Future directions

The overall goal is to develop and facilitate cultural, genetic, and chemical strategies for management of Phytophthora diseases on California strawberries. These strategies, along with similar ones for other soilborne disease complexes, should help lessen dependence upon methyl bromide fumigation. Work in progress includes:

- Enlarged field screening tests for Phytophthora resistance at MBA with cultivars Aromas, Camarosa, Diamante, Gaviota, Pacific, Pajaro, and Parker (last two used as standards).
- Evaluation of a Phytophthora resistance screening protocol at Wolfskill for the UC strawberry program.
- Determining the degree of agreement between field and greenhouse assessments of resistance to *Phytophthora*.
- Determining effects of irrigation intensity on development of Phytophthora crown rot.
- Determining efficacy of Ridomil Gold EC and Aliette WDG for control of Phytophthora crown rot (field experiment at MBA).

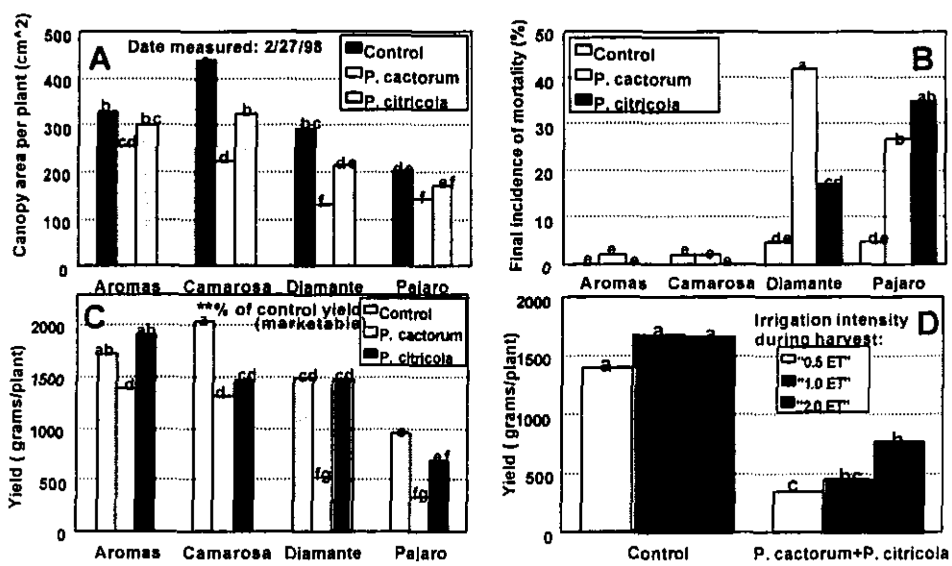


**Figure 1.** Relative susceptibility of some strawberry cultivars to: **A**, early season stunting; **B**, plant mortality, and **C**, yield depression caused by *Phytophthora cactorum* and *P. citricola*. **D**, effects of *P. cactorm* + *P. citricola* and irrigation intensity during harvest on total marketable fruit yield of cultivar Diamante.

# Bacterial Angular Leafspot (*Xanthomonas fragariae*) Disease of Strawberry Research (1998-1999)

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Bacterial angular leafspot (ALS) disease of strawberry is caused by *Xanthomonas fragariae* (Xf). Incidence of ALS has been widespread in California nurseries and fruit production fields in all major strawberry-producing regions of the state in recent years. Xf is a quarantine pest that is regulated by state, federal, and international phytosanitary regulations. The economic effects of ALS on plant growth, vigor, productivity, and yield under California conditions are not well documented.

Infection and disease development are favored by cool, wet conditions. Although chemical control of ALS is generally ineffective, sanitation (i.e. pathogen exclusion and/or eradication) is an important component of ALS disease management. However, implementation of effective sanitary practices to exclude or eliminate Xf is dependent upon understanding the epidemiology of Xf in California, and upon the ability to rapidly and reliably detect Xf in clinically asymptomatic plant material. Sources of infection in California nurseries and fruit production fields have not been clearly identified.

To address these issues, current research is focused on disease control (genetic resistance, chemical control), disease and pathogen epidemiology (nurseries and fruit production fields in California), and pathogen detection and identification (primarily in asymptomatic planting stock).

Commercial cultivars are being evaluated for their relative resistance/susceptibility of ALS in replicated and non-replicated plots in Watsonville (Monterey Bay Academy) and in replicated plots in Santa Maria. In general, there is a very broad range of relative ALS development on all short day and day neutral cultivars evaluated to date. There is some overlap of, and no statistically significant differences between, the ALS ratings most of the cultivars evaluated. However, in general, the short day cultivars generally develop less ALS than day neutral cultivars, at least under the conditions in California where these cultivars have been evaluated. Among the cultivars evaluated, the ALS ratings for Anaheim and Parker are significantly lower than those of other cultivars. On the other hand, the ALS ratings for Diamante and Pacific are significantly higher than those of other cultivars.

A small trial to evaluate the effect of Actigard on Xf infection and ALS development was conducted in a replicated plot in a high elevation nursery. The material was applied, according to the manufacturer's directions, at 7-10 intervals for 8 weeks beginning in late-July to newly emerging leaves. In October when the last readings were made, there were significantly fewer plants with ALS lesions on the treated plants than on the untreated plants. These preliminary results warrant further evaluation of this product as a potential component of the integrated management of ALS.

In 1998, viable Xf was demonstrated to survive epiphytically on the surface of asymptomatic strawberry leaves throughout most of the growing season. The relationship between strawberry genotype and the level of epiphytic Xf is not clear at this time. However, the level of epiphytic Xf recovered from the leaves of different cultivars was generally consistent with the relative cultivar resistance/susceptiblity. This will be continued in 1999. The temporal development (qualitative and quantitative) of endophytic microflora is being determined in tissue culture-derived strawberry plants (Camarosa) and in field-grown strawberry plants (Anaheim, Gaviota, Diamante) originating from a high elevation nursery.

In 1999, an attempt is being made to assess the relative growth, vigor, productivity and yield of plants harvested from non-diseased and ALS-affected mother plants in a high elevation California nursery in Watsonville (Monterey Bay Academy) and Santa Maria. At the initial rating, plants that originated from ALS-affected mother plants in the nursery were slightly, but probably not significantly, less vigorous than those plants harvested from non-diseased mother plants.

Improved detection and identification of Xf based on PCR-based technology is continuing. Several PCR primers are available. Accordingly, additional primers are not being developed at this time. The current work is focused on selective or semi-selective enrichment of low Xf levels, more efficient direct DNA extraction from clinical samples, and reduced analysis time. In conjunction with California Seed & Plant Lab. a BIO-PCR protocol is being developed to rapidly and reliably detect and identify low levels of Xf in clinically asymptomatic plant material.

# Management of Root Diseases and Rhizosphere Ecology of Strawberry

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Several approaches are currently under evaluation for management of root diseases of strawberry, including evaluation of alternative pesticides, alteration of crop rotation practices, and identifying host cultivars that are less susceptible to disease. A better understanding of specifically which pathogens are responsible for yield losses when plants are grown in poorly or nonfumigated fields will assist in developing these disease control strategies. In addition, a more comprehensive understanding of the types of organisms colonizing the roots of plants grown in fumigated compared to nonfumigated soils also would be helpful for developing alternative pest control strategies. This would include determining if detrimental root colonizers contribute to yield reductions in nonfumigated soil, as well as the identification of beneficial root colonizing organisms that might be capable of improving root health (either directly by stimulating root growth or indirectly by protecting against soilborne pathogens). The long-term objective of this project is to integrate the results of this research with ongoing trials evaluating alternative soil fumigants, crop rotation practices, and a screening program to develop biological control agents.

**1) Evaluation of pathogen involvement in growth and yield reduction.** A number of fungi have been recovered from necrotic roots of plants grown in nonfumigated soils collected from various farms in the central coastal area and are under evaluation for their effect on strawberry plants. The most emphasis has been placed on ***Pythium*** spp. and binucleate ***Rhizoctonia*, although *Cylindrocarpon*** and other fungal pathogens have been investigated as well. Trials conducted in greenhouse/growth chamber tests revealed different levels of virulence for the species examined; with some having negligible effects on root health. Trials assessing tolerance of different host cultivars to the most virulent pathogens are in progress. Field evaluations to determine the involvement of some of these pathogens on plant growth and yield reductions are included in this year' s field plots.

**2) The effect of crop rotation on pathogen population densities and strawberry root diseases.** A number of *strawbeny* root pathogens have a broad host range and are capable of infecting other crops, so in the absence of effective soil fumigation crop rotation can have a significant influence on maintaining populations of soilborne pathogens. Field trials evaluating the influence of rotation with broccoli, Brussels sprouts, or lettuce on the population dynamics of *Pythium* spp. and *Verticillium dahliae* are in progress at MBA. The field was cropped in vegetable rotation in the 1997 season, strawberry (Selva) in the 1998 season, and is presently in vegetable rotation. After harvesting the vegetable crops, the stubble was mowed with a flail mower, allowed to dry on the soil surface for several days and then incorporated into the soil. Two cropping cycles were planted for broccoli and lettuce and one for Brussels sprouts. While cropping practices had no consistent influence of population densities of *Pythium* spp., broccoli and Brussels sprouts reduced V.*dahliae* inoculum densities by 80-90% (to a final inoculum density of 1-2 microsclerotia/g soil). Although the market yield for all rotation treatments was significantly below the MB + Pic fumigated controls, strawberry grown in the broccoli rotation plots had only a 23% reduction in yield compared to Brussels sprouts and lettuce, which had yield reductions of 31% and 39%, respectively. Similar experiments (rotation with broccoli, cauliflower, or lettuce) also are underway at the Spence Rd. plots in Salinas. Cooperators on this project include Drs.Subbarao and Shetty and Steve Koike.

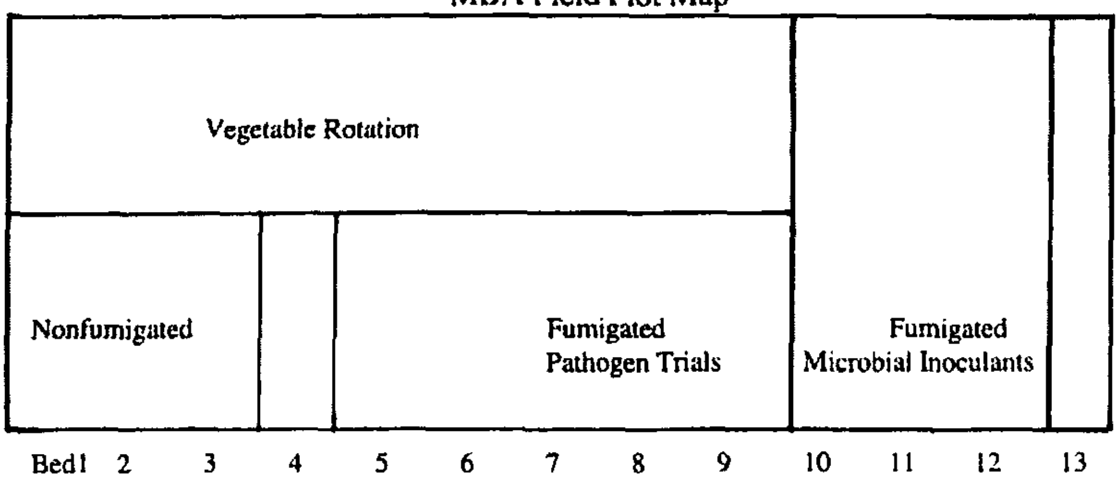
3) **Influence of root colonizers of root health, plant growth, and yield.** Preliminary investigations on the population structure and seasonal fluctuations of fungal, bacterial, and actinomycete root colonizers has been done for plants grown in fumigated and nonfumigated soils. A number of the recovered isolates have been evaluated for their effect on shoot and root growth in greenhouse/growth chamber trials. While most isolates had no effect on plant growth, some were identified that increased either shoot growth (up to a 40% increase), root growth (up to a 138% increase), or a general stimulatory effect on both shoot and root growth. Several isolates also were identified that had inhibitory effects on root growth (up to a 26% reduction). Trials last year

at the USDA test site off of Spence Rd. in Salinas in nonfumigated soil identified several beneficial isolates that significantly increased yield over the untreated control plants (one isolate gave a 35.5% increase in marketable yield) while other isolates appeared· to have a detrimental effect on yield. Trials are in progress this season at MBA in fumigated soil to evaluate the influence of these isolates on plant growth and yield when plants are grown in the absence of soilborne pathogens. Trials evaluating the efficacy of several commercial biological control agents are underway as well.

**Additional experimentation related to the plots at MBA**

- Field surveys of the central coastal production area to identify which root pathogens are present in the area and determine if there are fluctuations in the incidence of root infection during the production cycle.
- Greenhouse/growth chamber trials are underway to evaluate the susceptibility of 17 strawberry varieties to the root pathogens *Pythium* (several different species) and binucleate *Rhizoctonia* (3 anastomosis groups).
- Several field trials in progress at the USDA test plots off of Spence Rd. in Salinas. This site is naturally infested with a number of root pathogens (*Pythium*, binucleate *Rhizoctonia*, *Cylindrocarpon* spp., etc) with the exception of Verticillium wilt.
    - Evaluations of strawberry variety performance when plants are grown in nonfumigated compared to fumigated soil; currently 14 varieties are under evaluation.
    - Evaluating the influence of crop rotation on pathogen populations and disease severity, rotation crops include broccoli, cauliflower, and lettuce.
    - Evaluating the influence of microbial inoculants on plant growth and yield in fumigated and nonfumigated soil.
    - Evaluation of commercial biological control agents for enhanced plant growth and yield in fumigated and nonfumigated soil.

MBA Field Plot Map



**Summary of Recent Research on Verticillium wilt in High Elevation Strawberry Nurseries**


| T.R. Gordon | K.D. Larson | D.V. Shaw |
|---|---|---|
| Plant Pathology | Pomology Department | Pomology Department |
| U.C. Davis | U.C. Davis | U.C. Davis |


During 1998, research continued on the use of chemical fumigants and cover crops for control of Verticillium wilt, caused by *V. dahliae*, in high elevation strawberry nurseries. Six treatments were tested in a field experiment, which was initiated in 1995; each treatment had three replications, for a total of 18 plots. In one of these treatments, plots were kept fallow, while the other five treatments all had fall crops of rye in 1995 and 1996. Treatment two included spring plantings of mustard (canola), in 1996 and 1997, following incorporation of the fall rye crop. The mustard crops were cut and incorporated in the summer, and tarped for approximately one month. Treatments three through five had two years in rye followed by a chemical fumigation in August of 1997: either methyl bromide:chloropicrin (2:1) @ 350 pounds/acre, chloropicrin alone @ 250 pounds/acre, or C-35 (35% chloropicrin and 65% telone) @ 380 pounds/acre. The last treatment had two years in rye and no fumigation.

In April of 1998, all plots were planted to two strawberry cultivars, Camarosa and Selva. All fumigation treatments appeared to be equally effective in reducing soil populations of *V. dahliae*, which were undetectable (< 1 microsclerotium/gram of soil) in all the fumigated plots. Of the non-fumigated treatments, fallow had the lowest levels of *V. dahliae* (11 microsclerotia/gram), whereas the rye only and the rye/mustard treatments both had an average of 20 microsclerotia/gram. No disease was detectable in any of the fumigated plots. For Camarosa, 52, 56, and 76% of the plants had symptoms of Verticillium wilt in the rye, fallow, and rye/mustard treatments, respectively. For Selva, in both the rye and rye/mustard treatments, 87% of the plants were symptomatic, whereas 73% of the plants in fallowed plots had disease symptoms.

In summary, all the chemical fumigants provided adequate control of Verticillium wilt; whereas none of the non-chemical treatments was satisfactory. It should also be noted that fumigation experiments in previous years have shown less complete control with non-methyl bromide treatments. Thus chloropicrin alone or combined with telone may prove to less consistent than the standard methyl bromide:chloropicrin combination.

In terms of runner production in the nursery, methyl bromide: chloropicrin was the best treatment. For Selva, plots receiving this treatment produced an average of 1331 runners per plot. The C-35 treatment (1117 runners/plot) was not significantly different from methyl bromide:chlorpicrin but chloropicrin alone was significantly worse (920 runners/plot). Similar results were obtained for Camarosa, although in this case, C-35 was inferior tochloropicrin alone. These results indicate that the fumigants differ somewhat due to factors other than Verticillium. That is, although Verticillium wilt was not a problem in any of the fumigated plots, they differed in productivity. This may reflect the activity of other microorganisms in the soil that were differentially affected by the fumigants.

Runners representative from each of the nursery treatments have been planted at the South Coast field station (Camarosa) and at Watsonville (Selva) in order to evaluate any carry-over effects of the nursery treatments.

During 1999 we will also be evaluating the effects of post-harvest chilling treatments on high elevation nursery plants.

## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

<u>**Support for trials provided by:**</u>

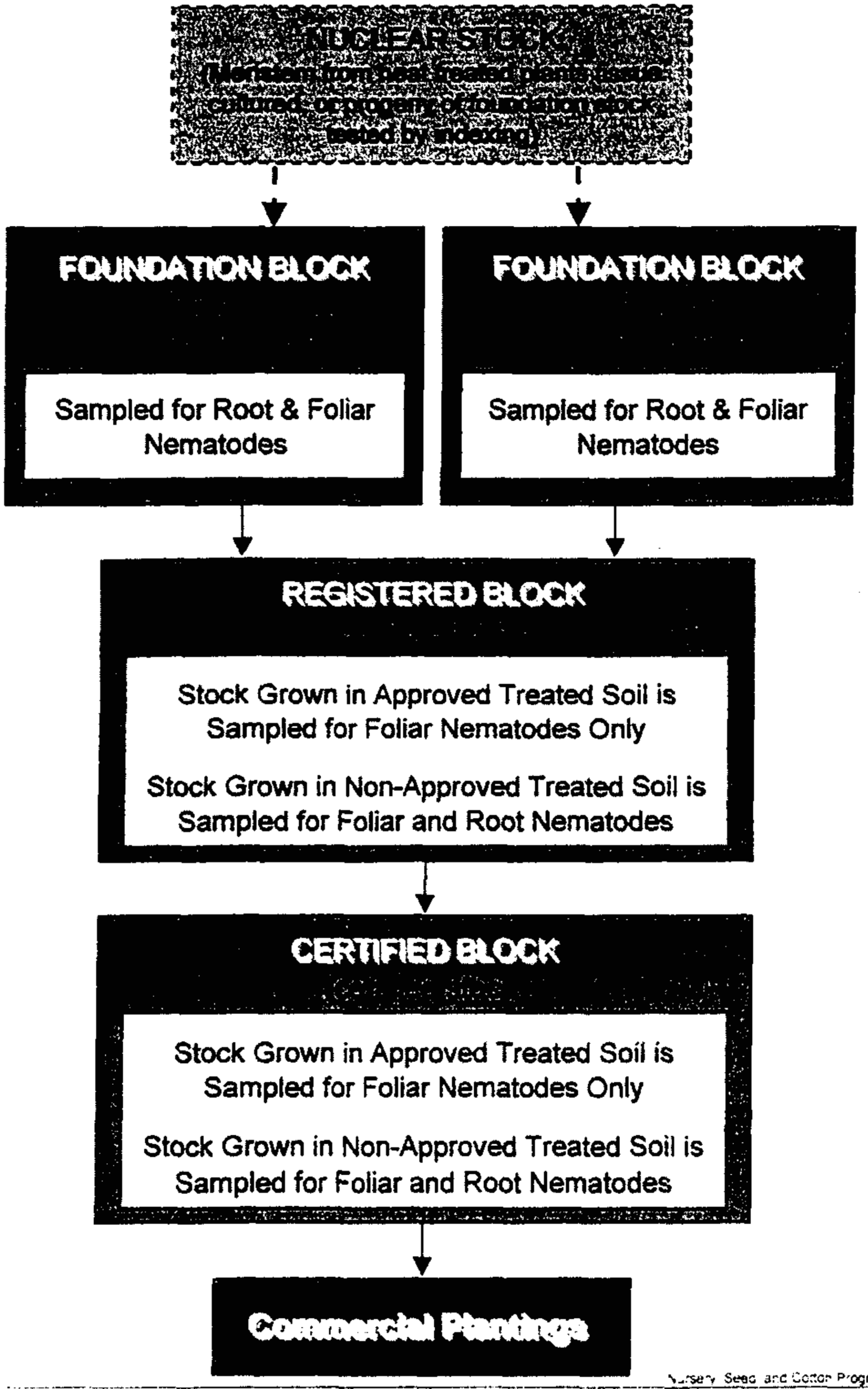
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Watsonville, California - Site #1

| | |
|---|---|
| Chloropicrin EC 24 gallons/acre<br>Standard tarp | Drip |
| Chloropicrin EC 24 gallons/acre<br>High barrier tarp | Drip |
| **Telone C35 EC 35 gallons/acre**<br>**Standard tarp** | Drip |
| **Telone C35 EC 35 gallons/acre**<br>**High barrier tarp** | Drip |
| Cholorpicrin 120 lbs acre<br>Standard tarp | Shank |
| Chloropicrin 200 lbs/acre<br>Standard tarp | Shank |
| Cholorpicrin 120 lbs acre<br>High barrier tarp | Shank |
| Chloropicrin 200 lbs/acre<br>High barrier tarp | Shank |
| Telone C35 210 lbs/acre<br>Standard tarp | Shank |
| **Telone C35 350 lbs/acre**<br>**Standard tarp** | Shank |
| Telone C35 210 lbs/acre<br>High barrier tarp | Shank |
| **Telone C35 350 lbs/acre**<br>**High barrier tarp** | Shank |
| MBr/Pic 67/33<br>Standard tarp | Shank |

250'

# STRAWBERRY PLANTS REGISTRATION & CERTIFICATION



HORTSCIENCE 30(2):236–237. 1995.



# Strawberry Nursery Soil Fumigation and Runner Plant Production

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*Additional index words.* chloropicrin, *Fragaria* ×*ananassa*, growth, methyl bromide, runner plants, stolons, trichloronitromethane

*Abstract.* **Three preplant soil fumigation treatments were applied on 5 Apr. 1993 to a nursery site that had not been planted previously to strawberries (*Fragaria* ×*ananassa* Duch.): 1) a mixture of 67 methyl bromide : 33 chloropicrin (CP) (by weight, 392 kg·ha$^{-1}$) (MBCP); 2) 140 kg CP/ha; and 3) nonfumigation (NF). On 26 Apr., cold-stored 'Chandler' and 'Selva' strawberry plants of registered stock were established in each treatment. Soil and root/crown disease symptoms were absent in all treatments during the course of the study. In October, runner plants were machine-harvested and graded to commercial standards. The cultivars produced a similar number of runners per mother plant. Fumigation with MBCP, CP, and NF resulted in 18.56, 15.75, and 7.89 runners per mother plant, respectively. For 'Selva', runner root and crown dry weights were similar for the MBCP and CP treatments, but NF resulted in significant reductions compared to the other two treatments. For 'Chandler', fumigation with CP resulted in reduced root dry weight, and NF resulted in reduced crown and root dry weights compared to fumigation with MBCP. The results demonstrate the marked decreases in strawberry runner production and runner size that can occur in the absence of preplant soil fumigation, even on new strawberry ground. Also, small, but significant, reductions in runner production and runner size may occur with CP applied at a rate of 140 kg·ha$^{-1}$ compared to standard fumigation with MBCP. Chemical name used: trichloronitromethane (chloropicrin).**

In California, ≈11,000 ha of strawberries produced a crop valued at about $450,000,000 in 1993 (California Processing Strawberry Advisory Board, 1993). As in other high-yielding strawberry production systems, California strawberries are grown in annual hill culture, which requires the production of ≈500,000,000 runner (stolon) plants in nurseries each year. About 90% of the California strawberry hectarage is planted to material grown in high-elevation (>1000 m elevation) nurseries (Voth and Bringhurst, 1990; Welch, 1989).

Strawberry nurseries in California use preplant soil fumigation with mixtures of methyl bromide and chloropicrin (CP) to enhance production of disease- and nematode-free runner plants and to control weeds. Preplant soil fumigation results in increased strawberry plant vigor and productivity, which have been attributed to two sources: 1) reduced plant mortality due to control or elimination of lethal pathogens, and 2) increased plant vigor due to the reduction or elimination of a highly variable complex of sublethal or competitive soil microorganisms (Wilhelm and Paulus, 1980). Although numerous studies have demonstrated the benefits of preplant soil fumigation for strawberry productivity (Himelrick and Dozier, 1991; Wilhelm et al., 1974; Wilhelm and Paulus, 1980; Yuen et al., 1991), most of these studies concerned performance of strawberry plants in fruiting fields, rather than runner production in nurseries.

Methyl bromide has been classified as an ozone-depleting compound (Watson et al., 1992), and the U.S. Environmental Protection Agency (EPA) requires a phase out of its production and use by the year 2001. In view of the EPA ruling, alternative technologies are needed to ensure the continued production of disease- and nematode-free plant material for strawberry, as well as other horticultural crops. Soil fumigation with CP controls many soil-borne fungal pathogens that are major limitations to growth and productivity in California strawberry nurseries and fruit production fields (Wilhelm, 1961); in addition, CP has some herbicidal activity (unpublished data, K.D. Larson et al., 1993). CP is registered for strawberry as a preplant soil fumigant and, therefore, is a possible alternative to soil fumigation with mixtures of methyl bromide and CP.

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## Materials and Methods

We conducted a study in a high-elevation strawberry nursery near Macdoel, Calif., (lat. 41.8°N, elevation 1300 m) to determine the influence of three preplant soil fumigation treatments, applied in the spring, on runner production: 1) a mixture of 67 methyl bromide : 33 CP (by weight, 392 kg·ha$^{-1}$) (MBCP); 2) 140 kg CP/ha; and 3) nonfumigation (NF). Treatments were applied on 5 Apr. 1993 by a commercial applicator. There were three replications per treatment, with each one measuring 3.35 × 30.5 m. The site had never been planted to strawberries; previous crops included sugar beets (*Beta vulgaris* L.), alfalfa (*Medicago sativa* L.), grain, and potatoes (*Solanum tuberosum* L.).

On 26 Apr., cold-stored 'Chandler' and 'Selva' mother plants were established in separate plots, each 3.35 × 3.66 m, in all treatments. There was concern that soil fumigation would result in greater runner plant population densities, resulting in reduced runner plant size compared to nonfumigation. Therefore, for each treatment and cultivar, mother plants were established using two plant spacings: the typical in-row plant spacing used for each cultivar in that nursery (30 cm for 'Selva', 36 cm for 'Chandler') and a wider in-row spacing that was 1.5× normal. The intention was to harvest plots from all three fumigation treatments that had similar runner plant densities, thereby avoiding runner size differences due to differences in plant density. There were two plots for each cultivar in each treatment/replicate, one plot for each spacing. Thus, the experiment design was a randomized complete block for treatment and cultivar, with mother plant spacing nested in treatment and cultivar. Fumigation treatments were replicated three times, for a total of 36 plots (three fumigation treatments, two cultivars, two spacings, three replications). Mother plants were established in double rows 91 cm apart. Following planting, normal nursery practices were employed through the growing season.

Adverse weather conditions during plantation establishment resulted in about a 15% mortality of mother plants, regardless of soil treatment. Symptoms of plant disease were absent in all treatments, and there was no effect of fumigation treatment on plant mortality during the remainder of the study. Thus, the main effect of fumigation in this study appeared to be the result of competition from sublethal soil organisms, rather than specific, lethal pathogens.

Entire plots of 'Chandler' and 'Selva' were machine-harvested on 8 and 17 Oct. 1993, respectively. All plants were graded to commercial standards, after which the number of marketable runners produced per plot and per mother plant was determined. For each cultivar and each spacing in each treatment replicate, 15 runners were randomly selected for determining crown and root dry weights (96 h at 60C). Due to differences in nursery digging dates, and hence differences in runner size for the two cultivars, dry weights were determined separately for each cultivar.

## Results and Discussion

There was a highly significant effect ($P \leq 0.01$) of soil fumigation on runner production (Table 1). Although there was a significant effect ($P \leq 0.05$) of mother plant spacing on the number of runners produced per plot, there were no effects of spacing or cultivar on the number of runners produced per mother plant

Table 1. Results for analysis of variance for strawberry runner production with two cultivars and two mother plant spacings in each of three soil fumigation treatments.

| Source | df | Mean squares: Runners/ plot | Runners/ mother plant | Root dry wt | Crown dry wt |
|---|---|---|---|---|---|
| Between subjects | 35 | | | | |
| Replication | 2 | 2710.75 | 10.85 | 0.47 | 0.046 |
| Fumigation (F) | 2 | 111578.58** | 367.10** | 7.09** | 0.383** |
| Cultivar (C) | 1 | 6889.00 | 5.07 | 19.92** | 0.829** |
| Error (a) | 10 | 2396.72 | 7.82 | 0.33 | 0.031 |
| Spacing (S) | 1 | 9344.44* | 13.00 | 1.05 | 0.006 |
| F × S | 2 | 291.69 | 2.97 | 0.44 | 0.001 |
| C × S | 1 | 136.11 | 1.34 | 0.05 | 0.033 |
| F × C × S | 2 | 963.86 | 2.14 | 0.30 | 0.030 |
| Error (b) | 14 | 1754.93 | 5.92 | 0.45 | 0.025 |

*,**Significant at $P \leq 0.05$ or 0.01, respectively.

Table 2. Soil fumigation treatment and mean runner production and mean crown and root dry weights for 'Selva' and 'Chandler' strawberry plants.

| Fumigant[y] | Runners/ mother plant[x] | Selva: Crown dry wt[z] (g) | Selva: Root dry wt (g) | Chandler: Crown dry wt (g) | Chandler: Root dry wt (g) |
|---|---|---|---|---|---|
| MBCP | 18.6 a[w] (0.77) | 1.71 a (0.07) | 4.31 a (0.31) | 1.42 a (0.06) | 2.66 a (0.19) |
| CP | 15.7 b (0.83) | 1.73 a (0.07) | 3.60 a (0.26) | 1.40 a (0.06) | 1.71 b (0.10) |
| NF | 7.9 c (0.43) | 1.40 b (0.06) | 2.42 b (0.19) | 1.10 b (0.05) | 1.49 b (0.10) |

[z]For crown and root dry weights, $n = 90$; SE are reported in parentheses.
[y]MBCP = methyl bromide : chloropicrin; CP = chloropicrin; NF = nonfumigated (control); see text for rates.
[x]Pooled means for both cultivars, $n = 12$; SE are reported in parentheses.
[w]Mean separation within columns by Tukey's Studentized range test, $P \leq 0.05$.

(Table 1). Therefore, for each fumigation treatment, runner production data were pooled for the two cultivars and the two spacings for determination of mean runner production per mother plant.

For CP and NF, runner production per mother plant was reduced 15% and 57%, respectively, compared to MBCP (Table 2). For 'Selva' plants, there were no significant differences in crown dry weights or root dry weights between MBCP and CP. However, for 'Chandler', root dry weight for CP was reduced relative to that of MBCP. For 'Selva', runner crown and root dry weights for NF were lower than for the other two treatments, despite the lower plant population density in the NF plots.

In the absence of methyl bromide, control of soilborne fungal pathogens with CP is best achieved when applied at rates of 360 kg·ha$^{-1}$ or higher (Wilhelm, 1961). However, due to the relatively low vapor pressure of CP, particularly in wet, cold conditions that occur in high-elevation nurseries in early spring, such rates may be phytotoxic if plantations are established soon after fumigation (K. Fowler, Tri-Cal, personal communication, 1993; C. Gaines, Lassen Canyon Nursery, personal communication, 1993).

Preplant soil fumigation with CP at 140 kg·ha$^{-1}$ resulted in significant increases in runner yield and runner size compared to NF, although yield and size were reduced compared to fumigation with a mixture of 67 methyl bromide : 33 chloropicrin (by weight, 392 kg·ha$^{-1}$). For NF, the marked reduction in runner production and size demonstrates the importance of preplant soil fumigation for enhancing runner production and runner quality in strawberry nurseries, even on new nursery ground.

Additional work is needed to evaluate the effect of soil fumigation with various rates of CP, applied in spring and fall, on strawberry runner production.

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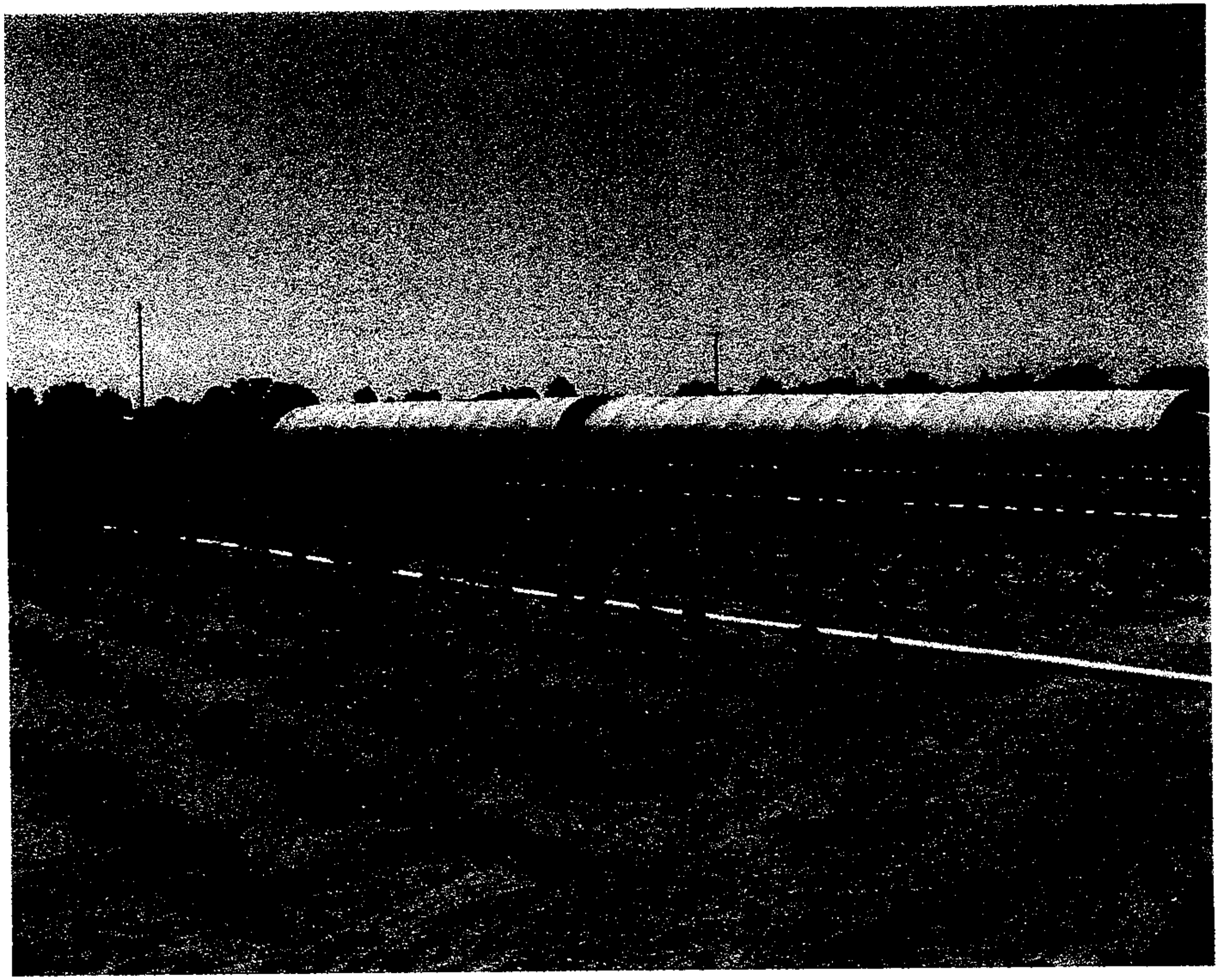


Photo 14. Low-elevation strawberry plant production nursery in the Central Valley (California) visited during the July, 1999 Methyl Bromide Alternatives tour.

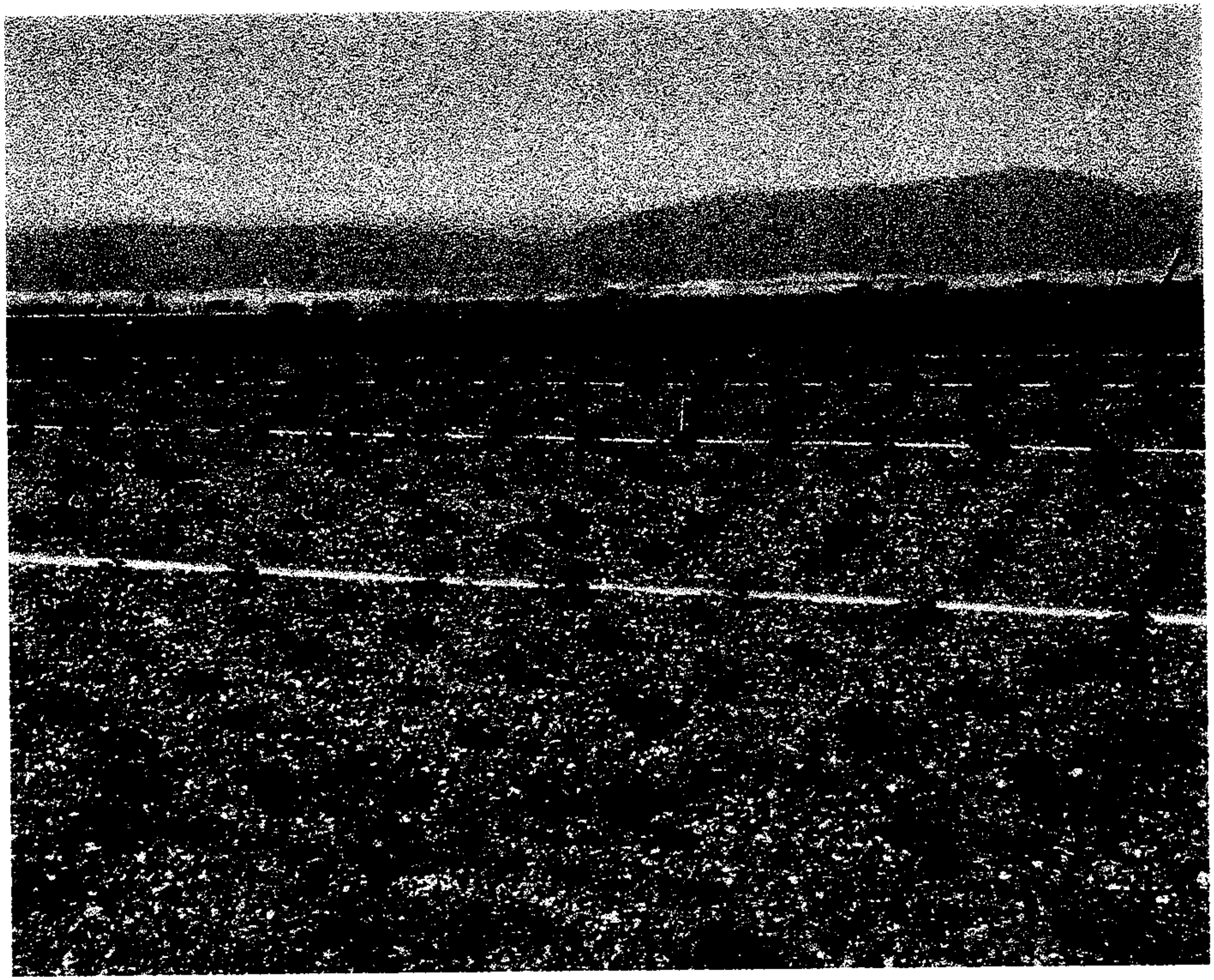


Photo 15. Strawberry plant production nursery near Orland, California visited during July, 1999 Methyl Bromide Alternatives tour.

Photo 16. USDA-ARS scientist Hussein Ajwa discusses reduced risk methyl bromide applications on-farm at Watsonville Site #1 during the July, 1999 Methyl Bromide Alternatives tour.

Photo 17. Strawberry grower shares observations on reduced risk application of fumigants using drip irrigation technology, at Watsonville Site #1 (California) during the July, 1999 Methyl Bromide Alternatives tour.

Photo 18. Strawberry growers discuss alternates to methyl bromide with Federal, state, and county officials, researchers from the University of California and the USDA, and other attendees from throughout California at Watsonville Site #2 during the July, 1999 Methyl Bromide Alternatives tour.

Photo 19. Federal and state regulators, USDA-ARS and University of California scientists, and California strawberry nurserymen and strawberry growers visit a strawberry nursery screenhouse during the July, 1999 Methyl Bromide Alternatives tour.

# Appendix D

## List of Technical Reports and Presentations Resulting from Project

**Scientific Reports of Research Completed During Grant Period**
**(Chronological Order)**


Duniway, J. M. 1998. Alternatives to methyl bromide for root disease management. Invited Papers Abstracts - Vol.1, 4.5.4S. 7th International Congress of Plant Pathology, Edinburgh, Scotland, August 9-16.

Duniway, J. M. 1998. Life after methyl bromide: Alternative approaches to controlling soilborne fungal diseases. Discussion Session E20, 7th International Congress of Plant Pathology, Edinburgh, Scotland, August 9-16.

Xiao, C. L., and Duniway, J. M. 1998. Bacterial population responses to soil fumigation and their effects on strawberry growth. Annual Meeting of the American Phytopathological Society, Las Vegas, NV, Nov 8-12. Phytopathology 88:S100 (Abstract).

Xiao, C. L., and Duniway, J. M. 1998. Frequency of isolation and pathogenicity of fungi on roots of strawberry in fumigated and nonfumigated soils. Annual Meeting of the American Phytopathological Society, Las Vegas, NV, Nov 8-12. Phytopathology 88:S100 (Abstract).

Duniway, J. M.., Xiao, and Gubler, W. D. 1998. Response of strawberry to soil fumigation: Microbial mechanisms and some alternatives to methyl bromide. Proceedings Annual International Conference on Methyl Bromide Alternatives and Emissions Reductions, Dec. 7-9, Orlando, FL; Abstract #6.

Ajwa, H. and Trout, T, Drip Application of Telone C35, Chloropicrin, and Vapam for Strawberry Production, *The Pink Sheet*, Strawberry News Bulletin, 99-5, March 30, 1999. Copy attached.

Duniway, J. M. 1999. Review of 1998 MBTOC Report; Plenary Session. Annual International Conference on Methyl Bromide Alternatives and Emissions Reductions, Nov. 1-4, San Diego, CA.

Duniway, J. M.., Xiao, C. L., Ajwa, H., and Gubler, W. D. 1999. Chemical and cultural alternatives to methyl bromide fumigation of soil for strawberry. Proceedings Annual International Conference on Methyl Bromide Alternatives and Emissions Reductions, Nov. 1-4, San Diego, CA; Abstract #2.

Pryor, A. 1999. Results of 2 years of field trials using ozone gas as a soil treatment. Proceedings Annual International Conference on Methyl Bromide Alternatives and Emissions Reductions, Nov. 1-4, San Diego, CA; Abstract #32.

**Other Scientific Reports of Research Completed During Grant Period Are in Preparation.**

**Presentations at Grower Meetings, Field Days, and Other Public Meetings.**

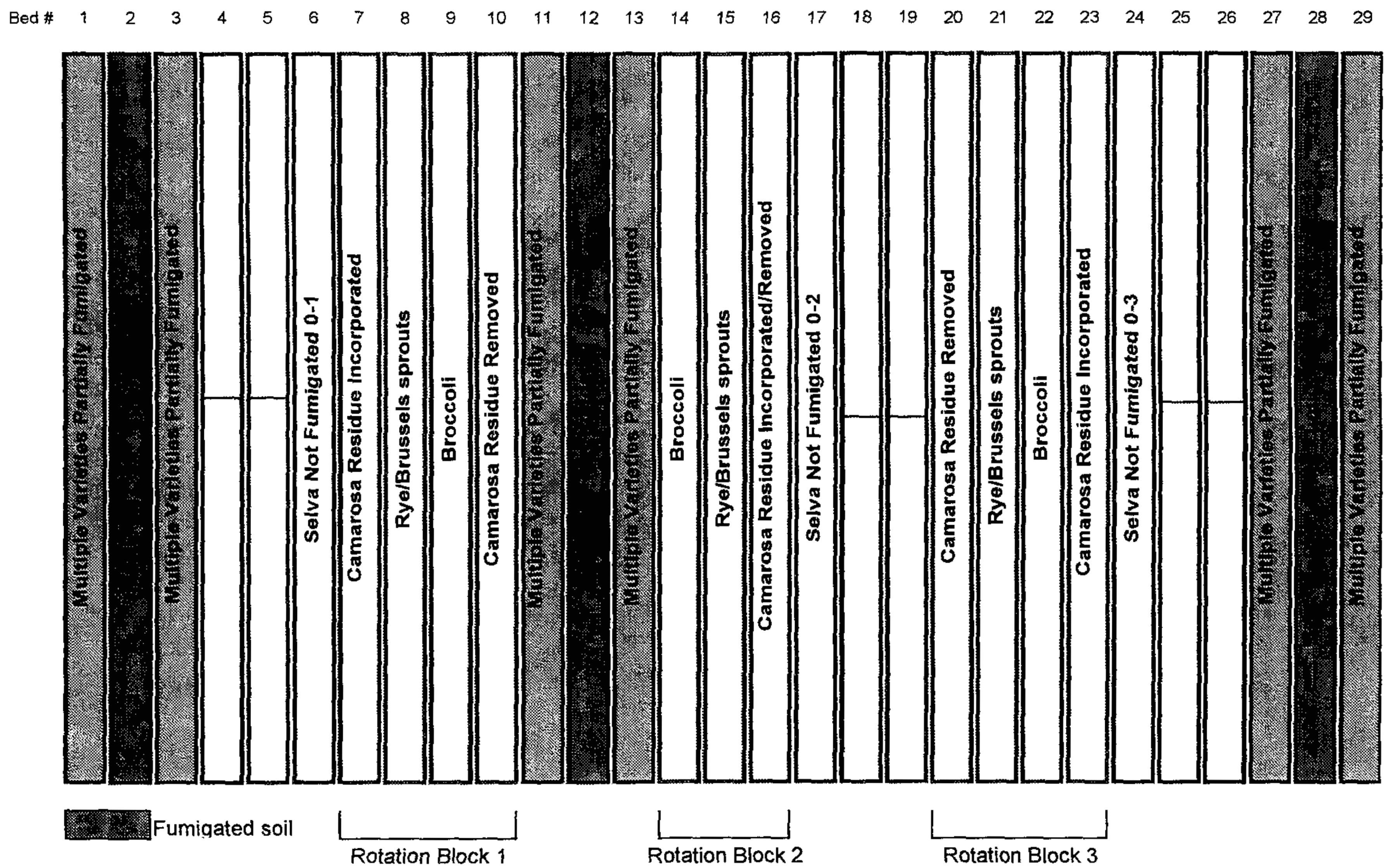
| | |
|---|---|
| May 5, 1998. | California Strawberry Commission Field Day, Monterey Bay Academy, Watsonville. |
| July 16, 1998. | California Strawberry Commission Research Committee Meeting. Monterey. |
| February 3, 1999. | Strawberry Research Conference, Watsonville. |
| February 10, 1999. | California Legislature Hearing, Assembly Committee on Agriculture, University of California, Davis. |
| March 10, 1999. | California Strawberry Industry Research Conference, UC South Coast Research & Education Center, Irvine. |
| April, 1999. | Strawberries Respond to Soil Fumigation: Microbial Mechanisms and Some Alternatives to Methyl Bromide. USDA Methyl Bromide Alternatives Newsletter, Vol. 5, No. 2, pages 10-12. |
| April 20-21, 1999. | ARS-USDA Methyl Bromide Alternatives National Program Workshop, Monterey, CA. |
| May 4, 1999. | Strawberry Field Day in Watsonville; Monterey Bay Academy Field Tour. |
| July 14, 1999. | California Strawberry Commission Research Committee Meeting, Monterey. |
| December 14, 1999. | Pest Science Conference (For PCAs), University of California, Davis. |

# Appendix E

## Site Maps:

1. Monterey Bay Academy Trials
2. Reduced Risk Application Method
3. On Farm Strawberry Methyl Bromide Alternatives Trials

# 1998-99 Monterey Bay Academy



# MBA Beds 30 to 53 as used in 1998-1999 Experimental Cycle

| Root dip Exp. | Verticillium Inoculum Experiment | | |
|---|---|---|---|
| SEL DIP | ID6 SEL | ID2 CAM | ID6 CAM |
| CAM DIP | ID6 CAM | ID2 SEL | ID6 SEL |
| CAM ND | ID5 CAM | ID4 SEL | ID1 SEL |
| SEL ND | ID5 SEL | ID4 CAM | ID1 CAM |
| SEL DIP | ID3SEL | ID6 CAM | ID3SEL |
| CAM DIP | ID3 CAM | ID6 SEL | ID3 CAM |
| SEL ND | ID4 CAM | ID5 SEL | ID5 CAM |
| SEL ND | ID4 SEL | ID5 CAM | ID5 SEL |
| CAM ND | ID1 CAM | ID1 SEL | ID4 SEL |
| SEL ND | ID1 SEL | ID1 CAM | ID4 CAM |
| SEL DIP | ID2 SEL | ID3 CAM | ID2 SEL |
| CAM DIP | ID2 CAM | ID3 SEL | ID2 CAM |
| 30 | 31 | 32 | 33 |

High Barrier Film Fumigation Experiment

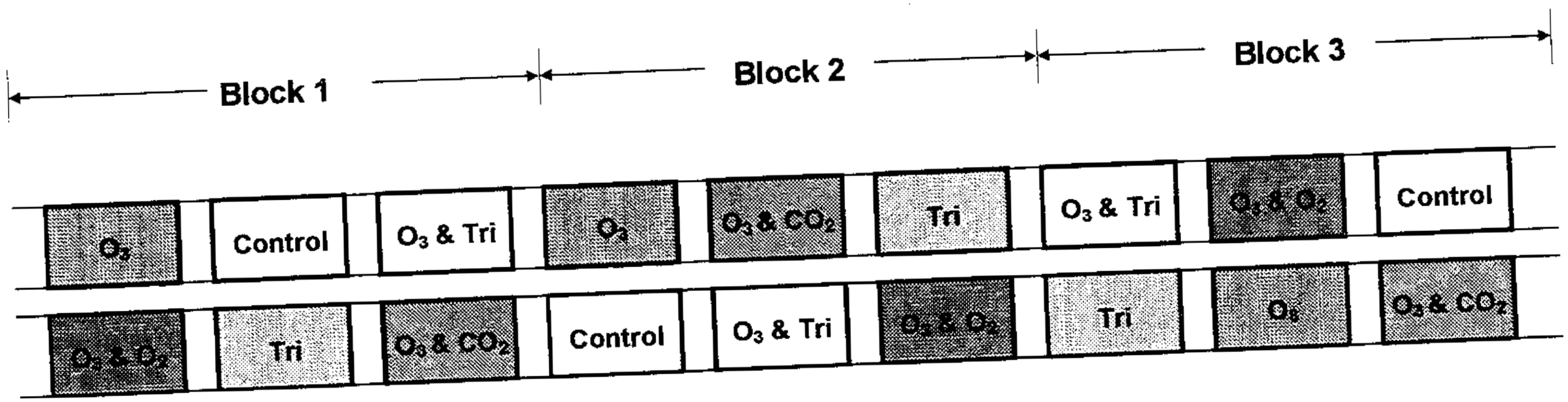
| | BLOCK 1 | | | | | | BLOCK 2 | | | | | | BLOCK 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HB | ST | HB | ST | ST | HB | ST | HB | ST | HB | HB | ST | HB | ST | ST | HB | HB | ST | | |
| | NT | NT | TC35 425 | TC35 425 | C 200 | C 200 | MBC 325 | MBC 325 | C 200 | C 200 | TC35 283 | TC35 283 | C 300 | C300 | TC35 425 | TC35 425 | NT | NT | | |
| | MBC 325 | MBC 325 | TC35 283 | TC35 283 | C 300 | C 300 | NT | NT | C 300 | C 300 | TC35 425 | TC35 425 | C 200 | C 200 | TC35 283 | TC35 283 | MBC 325 | MBC 325 | | |
| | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 |

Verticillium inoculum treatments
ID1=0 MS/gm soil (fumigated control)
ID2=0.5 MS/gm soil
ID3=2 MS/g soil
ID4=5 MS/g soil
ID5=10MS/g soil
ID6=30MS/g soil

bed 30 no fumigation
beds 31-33 bed fumigation with MBC 325
beds 34-52 fumigated as indicated
beds 52-53 non fumigated borders

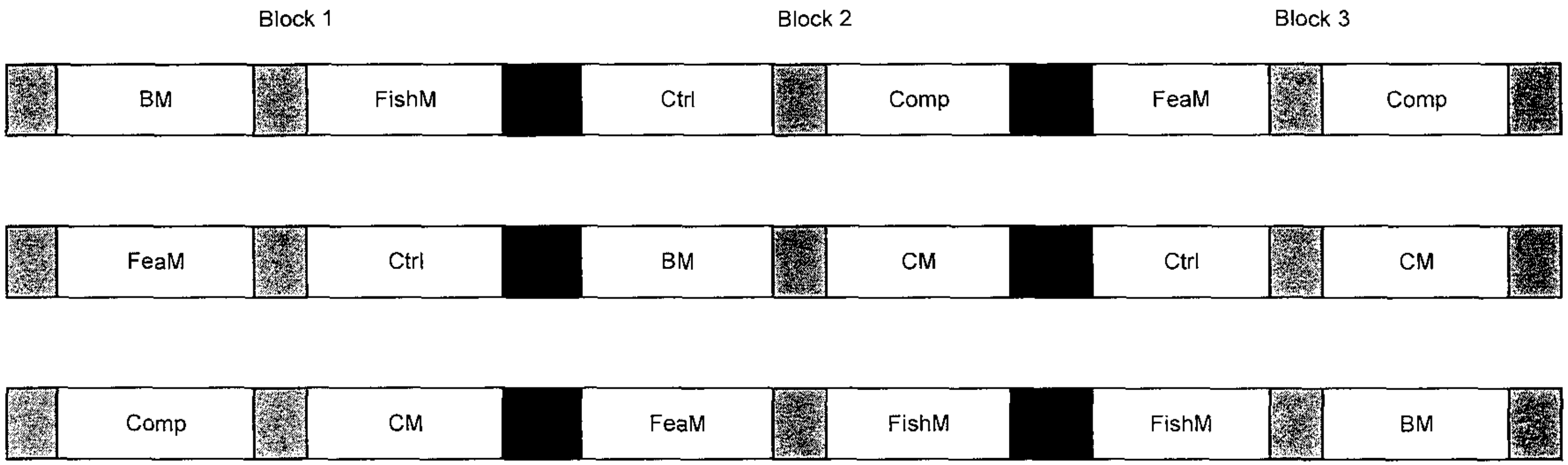
hb=high barrier film
st=standard film

# 1998-99 MBA -- Ozone Experiment



# Field plots for soil organic amendments experiment at MBA in 98-99

N




Treatments:
1. BM: Blood Meal @ 1% (w/w)
2. FishM: Fish Meal @ 1% (w/w)
3. FeaM: Feather Meal @ 1% (w/w)
4. CM: Chicken Manure @ 1% (w/w)
5. Comp: Compost @ 10 T/acre
6. Ctrl: Control (no amendment)

Plot size:
Each experiment unit=30'
3' gaps between units and 4' gaps between blocks

MBA 1998-99

[redacted]

## MBA 98 plots (Fumigated Sept 6-8, 1998)

| # | Irrig | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | (T13)-PicMw (25 mm) | (T9)-MvHw (35 mm) | (T5)-HtMw (25 mm) | (T12)-(Pic+Mv)Mw |
| 1 | M | [illegible] | High Telone C35 Shank | (T7)-MtMw (25 mm) | (T8)-HvMw (25 mm) | (T10)-MvMw (25 mm) | (T2)-MeBr/Pic Shank |
| 2 | L | [illegible] | High Telone C35 Shank | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) | (T13)-PicMw (25 mm) | (T6)-HtHw (35 mm) |
| 3 | H | [illegible] | High Telone C35 Shank | (T4)-HtLw (15 mm) | (T12)-(Pic+Mv)Mw | (T8)-HvMw (25 mm) | (T9)-MvHw (35 mm) |
| 4 | H | High Telone C35 Shank | [illegible] | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank | (T5)-HtMw (25 mm) |
| 5 | M | High Telone C35 Shank | [illegible] | (T11)-(Mt+Mv)Mw | (T1)-Untreated control | (T12)-(Pic+Mv)Mw | (T4)-HtLw (15 mm) |
| 6 | L | High Telone C35 Shank | [illegible] | (T9)-MvHw (35 mm) | (T3)-Telone/Pic Shank | (T1)-Untreated control | (T11)-(Mt+Mv)Mw |
| 7 | M | [illegible] | High Telone C35 Shank | (T1)-Untreated control | (T4)-HtLw (15 mm) | (T6)-HtHw (35 mm) | (T7)-MtMw (25 mm) |
| 8 | H | [illegible] | High Telone C35 Shank | (T5)-HtMw (25 mm) | (T13)-PicMw (25 mm) | (T7)-MtMw (25 mm) | (T3)-Telone/Pic Shank |
| 9 | L | [illegible] | High Telone C35 Shank | (T12)-(Pic+Mv)Mw | (T2)-MeBr/Pic Shank | (T2)-MeBr/Pic Shank | (T10)-MvMw (25 mm) |
| 10 | M | High Telone C35 Shank | [illegible] | (T10)-MvMw (25 mm) | (T11)-(Mt+Mv)Mw | (T9)-MvHw (35 mm) | (T8)-HvMw (25 mm) |
| 11 | L | High Telone C35 Shank | [illegible] | (T3)-Telone/Pic Shank | (T6)-HtHw (35 mm) | (T11)-(Mt+Mv)Mw | (T1)-Untreated control |
| 12 | H | High Telone C35 Shank | [illegible] | (T8)-HvMw (25 mm) | (T5)-HtMw (25 mm) | (T4)-HtLw (15 mm) | (T13)-PicMw (25 mm) |
| | | 35 ft | 35 ft | 31 ft | 31 ft | 31 ft | 31 ft |

## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

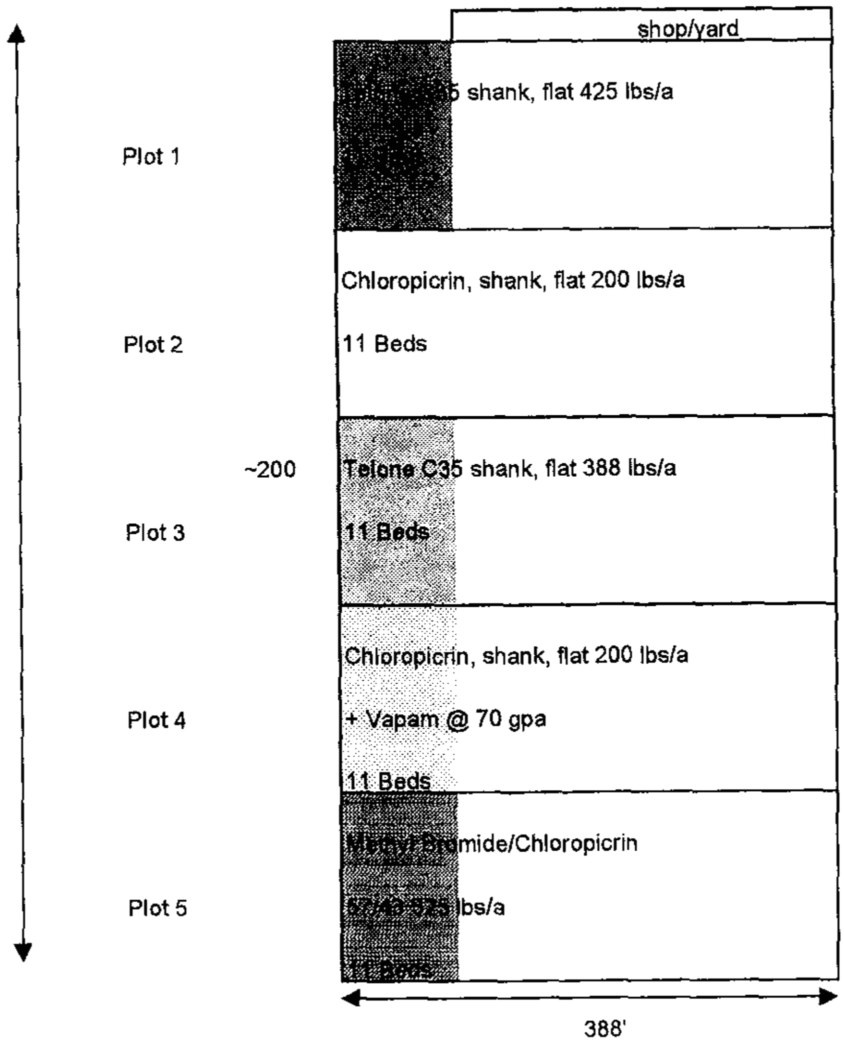
**Support for trials provided by:**

*California Strawberry Commission*

United States Department of Agriculture/Agricultural Research Service

California Department of Pesticide Regulation, *Pest Managemant Alliance Program*

Trial location: Oxnard, California - Site #1



# 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**

*California Strawberry Commission*

United States Department of Agriculture/Agricultural Research Service

California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Oxnard, California - Site #2

400 feet | 400 feet

## Rep #1 — ROAD

Block #1

| | | |
|---|---|---|
| 1 | Nonfumigated | 1 |
| 2 | MBr/Pic 75/25 - 330 #/a | 2 |
| 3 | Chloropicrin - low 120 #/a | 3 |
| 4 | Chloropicrin - high 200 #/a | 4 |
| 5 | Telone C35 - low 240 #/a | 5 |
| 6 | Telone C35 - high 350 #/a | 6 |
| 7 | Telone C35EC - low 21 gal/a | 7 |
| 8 | Telone C35EC - high 35 gal/a | 8 |
| 9 | Chloropicrin EC - low 12 gal/a | 9 |
| 10 | Chloropicrin EC - high 20 gal/a | 10 |

Block #2

| | | |
|---|---|---|
| 31 | Nonfumigated | 11 |
| 32 | MBr/Pic 75/25 - 330 #/a | 12 |
| 33 | Chloropicrin - low 120 #/a | 13 |
| 34 | Chloropicrin - high 200 #/a | 14 |
| 35 | Telone C35 - low 240 #/a | 15 |
| 36 | Telone C35 - high 350 #/a | 16 |
| 37 | Telone C35EC - low 21 gal/a | 17 |
| 38 | Telone C35EC - high 35 gal/a | 18 |
| 39 | Chloropicrin EC - low 12 gal/a | 19 |
| 40 | Chloropicrin EC - high 20 gal/a | 20 |

## Rep #2 — ROAD

Block #3

| | | |
|---|---|---|
| 20 | Chloropicrin EC - high 20 gal/a | 11 |
| 18 | Telone C35EC - high 35 gal/a | 12 |
| 17 | Telone C35EC - low 21 gal/a | 13 |
| 19 | Chloropicrin EC - low 12 gal/a | 14 |
| 12 | MBr/Pic 75/25 - 330 #/a | 15 |
| 11 | Nonfumigated | 16 |
| 14 | Chloropicrin - high 200 #/a | 17 |
| 13 | Telone C35 - high 350 #/a | 18 |
| 16 | Chloropicrin - low 120 #/a | 19 |
| 15 | Telone C35 - low 240 #/a | 20 |

Block #4

| | | |
|---|---|---|
| 41 | Chloropicrin EC - high 20 gal/a | 10 |
| 42 | Telone C35EC - high 35 gal/a | 8 |
| 43 | Chloropicrin EC - low 12 gal/a | 9 |
| 44 | Telone C35EC - low 21 gal/a | 7 |
| 45 | Nonfumigated | 1 |
| 46 | MBr/Pic 75/25 - 330 #/a | 2 |
| 47 | Telone C35 - high 350 #/a | 6 |
| 48 | Chloropicrin - high 200 #/a | 4 |
| 49 | Chloropicrin - low 120 #/a | 3 |
| 50 | Telone C35 - low 240 #/a | 5 |

## Rep #3 — ROAD

Block #5

| | | |
|---|---|---|
| 9 | Chloropicrin EC - low 12 gal/a | 21 |
| 7 | Telone C35EC - low 21 gal/a | 22 |
| 8 | Telone C35EC - high 35 gal/a | 23 |
| 10 | Chloropicrin EC - high 20 gal/a | 24 |
| 2 | MBr/Pic 75/25 - 330 #/a | 25 |
| 5 | Telone C35 - low 240 #/a | 26 |
| 4 | Chloropicrin - high 200 #/a | 27 |
| 1 | Nonfumigated | 28 |
| 3 | Chloropicrin - low 120 #/a | 29 |
| 6 | Telone C35 - high 350 #/a | 30 |

Block #6

| | | |
|---|---|---|
| 51 | Telone C35EC - high 35 gal/a | 18 |
| 52 | Chloropicrin EC - high 20 gal/a | 20 |
| 53 | Chloropicrin EC - low 12 gal/a | 19 |
| 54 | Telone C35EC - low 21 gal/a | 17 |
| 55 | Chloropicrin - low 120 #/a | 13 |
| 56 | Telone C35 - high 350 #/a | 16 |
| 57 | Telone C35 - low 240 #/a | 15 |
| 58 | Chloropicrin - high 200 #/a | 14 |
| 59 | MBr/Pic 75/25 - 330 #/a | 12 |
| 60 | Nonfumigated | 11 |

High barrier tarp

Standard tarp

Drip applied treatment

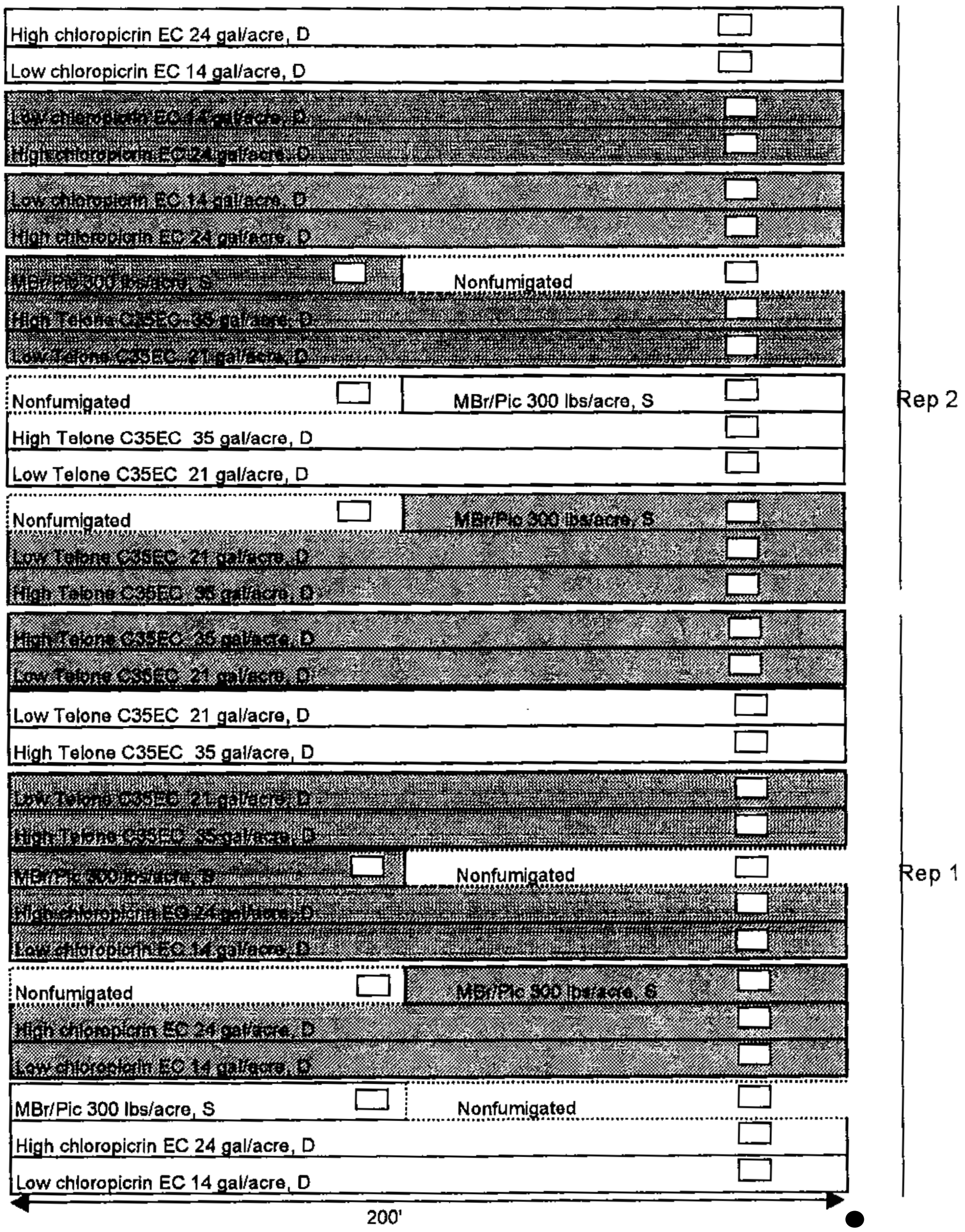
or

# 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Santa Maria, California

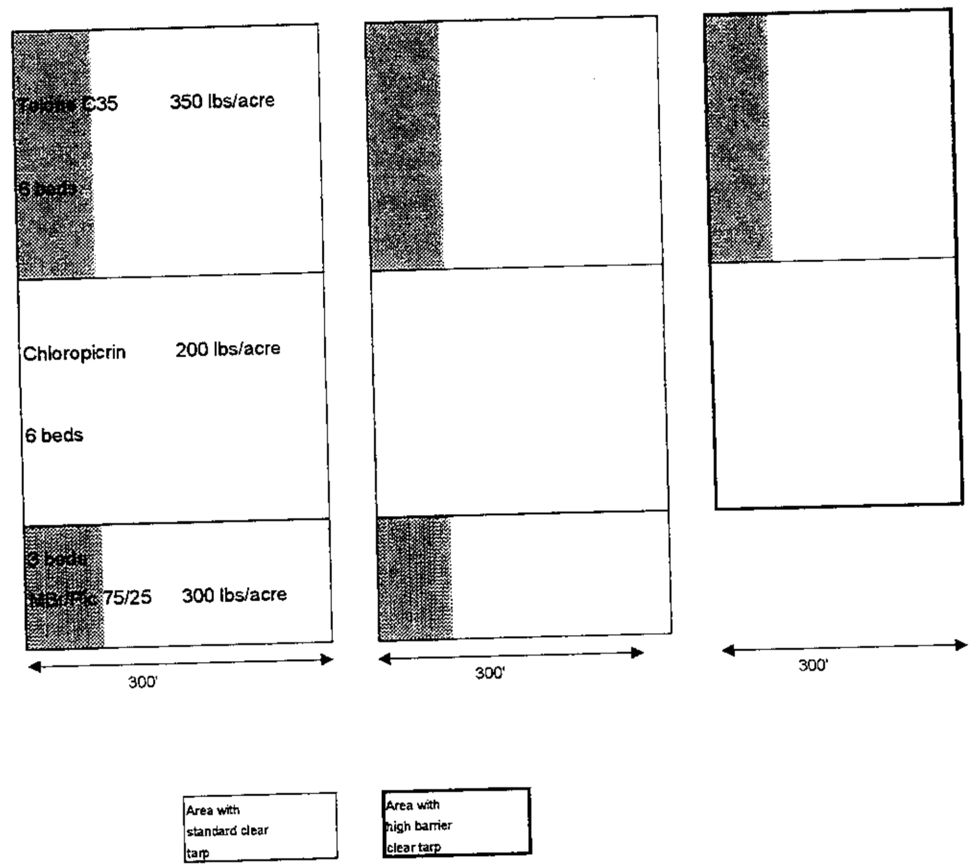
| Fumigants | Tarps |
|---|---|
| 1 High chloropicrin EC 24 gal/acre, D | |
| 2 Low chloropicrin EC 14 gal/acre, D | Clear standard tarp |
| 3 High Telone C35EC 35 gal/acre, D | Clear virtually impermeable film tarp |
| 4 Low Telone C35EC 21 gal/acre, D | Black standard tarp |
| 5 Nonfumigated | D = Drip applied |
| 6 MBr/Pic 300 lbs/acre, S | S = Shank applied |



**1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials**

<u>**Support for trials provided by:**</u>
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Santa Maria, California



## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Watsonville, California - Site #1

| | |
|---|---|
| Chloropicrin EC 24 gallons/acre<br>Standard tarp | Drip |
| Chloropicrin EC 24 gallons/acre<br>High barrier tarp | Drip |
| Telone C35 EC 35 gallons/acre<br>Standard tarp | Drip |
| Telone C35 EC 35 gallons/acre<br>High barrier tarp | Drip |
| Cholorpicrin 120 lbs acre<br>Standard tarp | Shank |
| Chloropicrin 200 lbs/acre<br>Standard tarp | Shank |
| Cholorpicrin 120 lbs acre<br>High barrier tarp | Shank |
| Chloropicrin 200 lbs/acre<br>High barrier tarp | Shank |
| Telone C35 210 lbs/acre<br>Standard tarp | Shank |
| Telone C35 350 lbs/acre<br>Standard tarp | Shank |
| Telone C35 210 lbs/acre<br>High barrier tarp | Shank |
| Telone C35 350 lbs/acre<br>High barrier tarp | Shank |
| MBr/Pic 67/33<br>Standard tarp | Shank |

250'

## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**

California Strawberry Commission

United States Department of Agriculture/Agricultural Research Service

California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Watsonville, California - Site #2

| | | |
|---|---|---|
| Telone C35 EC 35 gallons/acre | Standard **GREEN** tarp | Drip |
| Telone C35 EC 35 gallons/acre | Standard clear tarp | Drip |
| Telone C35 EC 35 gallons/acre | High barrier clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre | Standard clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre | High barrier clear tarp | Drip |
| Cholorpicrin EC 24 gallons/acre | Standard **GREEN** tarp | Drip |
| MBr/Pic 67/33 | Standard **GREEN** tarp | Shank |

215'

The below treatments are located on another section of the farm.

| | | |
|---|---|---|
| Telone C35 350 lbs/acre | Standard **GREEN** tarp | Shank |
| Cholorpicrin 200 lbs/acre | Standard **GREEN** tarp | Shank |

## 1998-1999 On Farm Strawberry Methyl Bromide Alternatives Trials

**Support for trials provided by:**
California Strawberry Commission
United States Department of Agriculture/Agricultural Research Service
California Department of Pesticide Regulation, Pest Managemant Alliance Program

Trial location: Irvine, California